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AN ASSESSMENT OF LONG-TERM CHANGES IN ANTHROPOMETRIC DIMENSIONS: SECULAR TRENDS OF U.S. ARMY MALES

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Data from the most recent US Army Anthropometric Survey provide a unique opportunity to assess long-term changes in body dimensions within the Army population. This report describes ~~these secular trends~~ for 22 body dimensions in four racial/cultural groups: Whites, Blacks, Hispanics and Asian/Pacific Islanders.

Individuals were grouped by birth year into 12 five-year cohorts, which span the years 1911 to 1970. Rates of change were calculated by regressing age-adjusted dimensions against cohort. Analyses of these relationships showed that almost all dimensions sustained statistically significant linear trends, the few exceptions being found within the Asian/Pacific Islanders group. Furthermore, except for the Asian/Pacific Islanders, the greatest relative rates of change were found in dimensions related to soft tissue development rather than skeletal dimensions. This pattern is consistent with the recent

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American cultural emphasis on health and physical fitness. The markedly different patterns seen in Asian/Pacific Islanders were best explained by immigration: they have experienced a linear increase in the proportion of foreign born members.

Finally, a method of applying these models to predict anthropometric dimensions of future Army populations is presented. The influence of demographic composition upon expected anthropometric distributions is demonstrated by predicting dimension values for six potential Army populations in the year 2023. The utility, and limitations, of these models for predicting future anthropometric dimensions are also discussed.

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PREFACE

This report is an outgrowth of research associated with the recent US Army Anthropometric Survey (ANSUR). As such, it represents one of the first attempts to use these data to address a critical anthropological research question.

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1. INTRODUCTION

A secular trend is a progressive change correlated with time. Secular trends of human morphological traits spanning the last 200 years are well documented (Davenport and Love, 1921; Morant, 1950; Trotter and Gleser, 1951b; Karpinos, 1958; Newman, 1963; Bawkin and McLauglin, 1964; Damon, 1965; 1968; Polednak, 1975; Meredith, 1976; McCullough, 1982; Tanner, et al., 1982; Bradtmiller, et al., 1985; Steegman, 1985; Takahashi, 1986; Ohyama, et al., 1987; Harlan, et al., 1988; Takamura, et al., 1988; Cline, et al., 1989). These descriptions focus on changes in adults, adolescents, or children. Generally, these trends are descriptions of changes in stature, weight, or the various milestones of maturity. Few reports discuss more than a handful of anthropometric dimensions. Data are now available from several anthropometric surveys of the US Army (Newman and White, 1951; White and Churchill, 1971; Gordon et al., 1989). These data provide a basis for an analysis of secular change in a myriad of human body dimensions.

Many factors contribute to secular trends of anthropometric dimensions. Although the root cause of secular trends remains unknown, some of the more commonly cited possibilities are: improved health, improved nutrition, changing rates of growth and maturation, assortative mating, immigration resulting in new population mixtures, immigration resulting in heterosis, changes in socioeconomic status, and changing cultural attitudes about physical fitness (Schreider, 1967; Meredith, 1976; Frisancho, 1977; Bielicki, et al., 1981; Flegal, et al., 1988; Lasker and Mascie-Taylor, 1989). A complication exists in that, generally, these causes refer to populations -- groups of interbreeding individuals. The Army, however, is not a population in that sense, but rather a subsample of the population of the United States. Because the Army is a reflection of that population, some of its secular trends will be derived from the same root causes. However, Army trends will also be affected by changes in the Army's criteria for anthropometric standards, changes in the way the Army samples the main population (i.e., a draft versus an all-volunteer Army), and changes in reasons for volunteering.

The Army anthropometric surveys also collected data on age and race. Therefore, questions on how rates of change compare among racial subgroups can be addressed. A preliminary investigation of these questions (Bradtmiller, et al., 1985) shows that statistically significant changes, in relation to age and race, occurred for many body dimensions in the US Army population. Therefore, the potential influence of these trends on problems of sizing and design should be investigated. The aims of this analysis are to: 1) quantitatively describe the secular trends of different dimensions for several racial/cultural groups; 2) contrast the rates of change among those groups; 3) identify the group(s) that are undergoing the greatest secular changes; 4) identify particular dimensions that are showing the highest rates of change; 5) use these results to determine when measurable changes will occur in particular dimensions; and 6) use these results to predict the anthropometric values of a future Army population.

2. METHODS

Data used in the analysis of male trends comes from the 1966 and 1988 anthropometric surveys of US Army men. A comparison of the measuring techniques used in these two surveys (White and Churchill, 1971 and Clauser, et al., 1988) showed that there were 22 exactly comparable dimensions that can be investigated for secular trends (see Figure 1). Although the 1966 survey did not collect data on race, Bradtmiller, et al. (1985) outline a method for converting data on national origin into racial identifications. Therefore, this method was used, along with the race data collected in the 1988 survey, to sort the data into four racial/cultural groups: Whites, Blacks, Hispanics, and Asians/Pacific Islanders. Based on these groupings, 88 distinct models of secular change were derived for US Army men.

Long-term trends were quantified using regression analysis. Because there are only two data sets and because a model constructed from only two values is inappropriate, the data were reorganized to develop meaningful models. Individuals were grouped into cohorts that represent five year birth intervals (see Tables 1 and 2). This procedure divided the data from the two surveys into 13 usable birth-year cohorts. However, both birth year and age at measurement vary within and between the surveys. Therefore, cohort dimensions will vary for several reasons. Among the more important reasons are: 1) Observer error and methodological differences; 2) Age related changes; and 3) Secular trends. Because the analysis of secular trends is the crux of this investigation, the first two effects should be controlled.

Only measurements obtained through strictly comparable techniques were analyzed for secular trends. This careful check of comparability should minimize the effects of methodological differences. The influence of observer error, however, cannot be directly controlled. Instead, information on allowable observer error from the 1988 survey (Clauser et al., 1988) was used as a guide to determine the relevance of observed "secular" change. Although an observed change might be statistically significant, if it is not greater than the allowable observer error it may not be meaningful.

Ideally, regression analyses should be conducted using samples of equal variance. This is, however, rarely the case in studies of secular trends. To overcome this problem the mean value for each body dimension was calculated for each cohort, and these were submitted to regression analysis. This method is commonly used in secular change studies to overcome the limitations imposed by traditional regression analyses (Trotter and Gleser, 1951a; 1951b; Newman, 1963; Bawkin and McLauglin, 1964; Hertzog, et al., 1969; Polednak, 1975; Himes and Mueller, 1977; Relethford and Lees, 1981; Borkan, et al., 1983; Price, et al., 1987). To accommodate very large differences in sample sizes for each cohort, each cohort's mean value was weighted by cohort size in the statistical analyses.

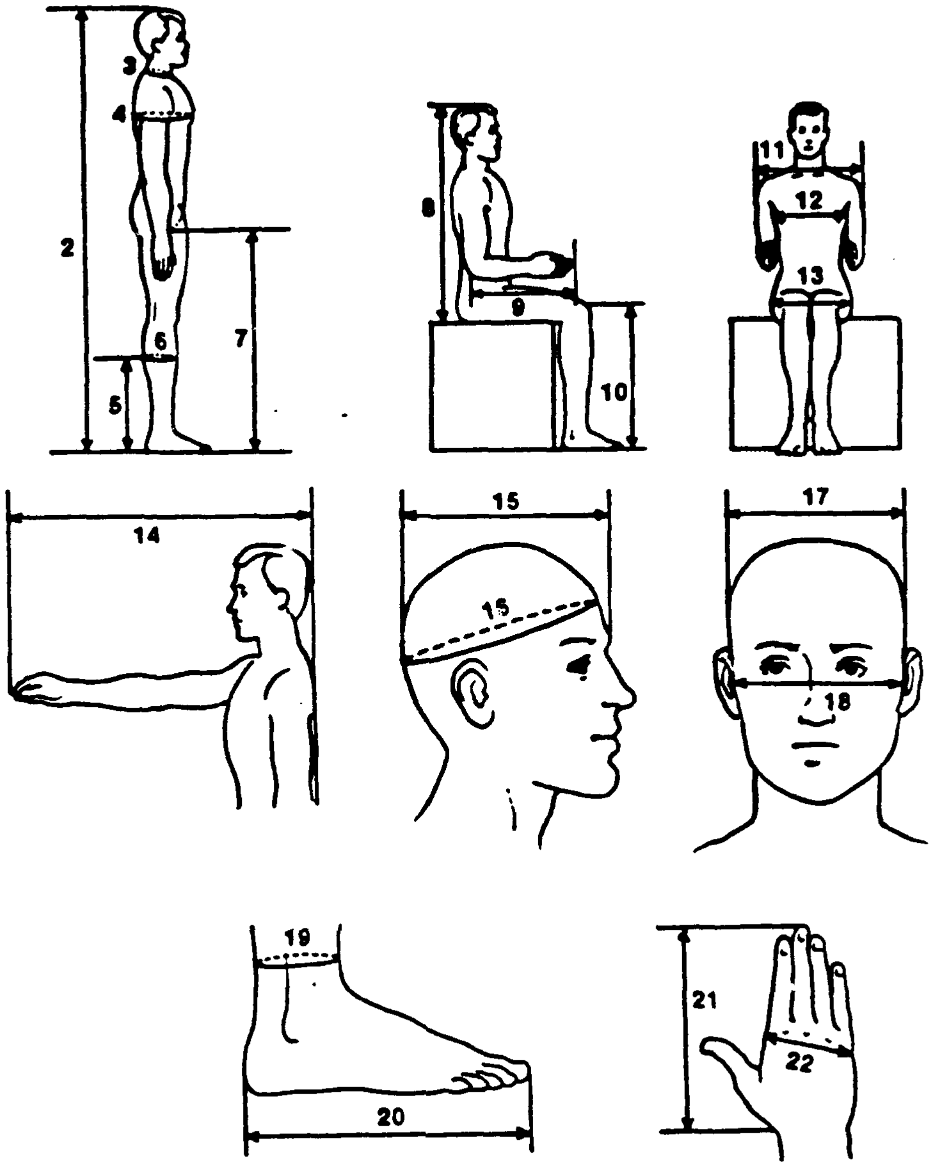

Figure 1. Visual guide to the anthropometric dimensions.

Measurement Key:

1. Weight
2. Stature
3. Neck Circumference
4. Chest Circumference
5. Calf Height
6. Calf Circumference
7. Crotch Height
8. Sitting Height
9. Forearm-Hand Length
10. Knee Height, Sitting
11. Bideltoid Breadth
12. Chest Breadth
13. Hip Breadth, Sitting
14. Thumbtip Reach
15. Head Length
16. Head Circumference
17. Head Breadth
18. Bizygomatic Breadth
19. Ankle Circumference
20. Foot Length
21. Hand Length
22. Hand Breadth

TABLE 1.
Cohort Breakdown by Age and Birth - Year

Cohort	Birth - Year Interval	Subjects' Ages According to Survey Year	
		1988	1966
4	1900-1904		-62
5	1905-1909		61-57
6	1910-1914		56-52
7	1915-1919		51-47
8	1920-1924	-64	46-42
9	1925-1929	63-59	41-37
10	1930-1934	58-54	36-32
11	1935-1939	53-49	31-27
12	1940-1944	48-44	26-22
13	1945-1949	43-39	21-17
14	1950-1954	38-34	16-
15	1955-1959	33-29	
16	1960-1964	28-24	
17	1965-1969	23-19	
18	1970-1974	18-	
19	1975-1979		
20	1980-1984		
21	1985-1989		
22	1990-1994		
23	1995-1999		
24	2000-2004		
25	2005-2009		

TABLE 2
Cohort Data Breakdown by Racial/Cultural Group

1966 Survey Data		Whites		Blacks		Hispanics		Asian/Pacific Islanders	
Cohort	Birth Years	N	Mean Age	N	Mean Age	N	Mean Age	N	Mean Age
6	1910-1914	7	53.6	3	53.3	0		0	
7	1915-1919	7	48.7	4	48.3	3	51.0	0	
8	1920-1924	20	43.4	10	43.6	2	44.5	1	45.0
9	1925-1929	63	38.3	24	38.2	3	38.3	2	38.0
10	1930-1934	107	34.2	35	33.9	17	34.3	2	34.5
11	1935-1939	101	28.7	57	28.8	11	28.7	3	29.0
12	1940-1944	752	23.3	231	23.5	97	23.0	5	23.0
13	1945-1949	1265	19.8	385	19.7	115	19.9	19	20.0

1988 Survey Data		Whites		Blacks		Hispanics		Asian/Pacific Islanders	
Cohort	Birth Years	N	Mean Age	N	Mean Age	N	Mean Age	N	Mean Age
10	1930-1934	1	55.0	0		0		0	
11	1935-1939	0		3	50.7	2	50.0	3	50.3
12	1940-1944	15	45.6	13	45.0	15	44.9	17	45.3
13	1945-1949	97	40.3	62	40.5	48	40.5	43	40.8
14	1950-1954	171	36.0	151	35.9	120	35.5	72	35.5
15	1955-1959	241	30.9	252	20.9	183	30.8	91	30.8
16	1960-1964	406	25.8	356	25.9	257	25.9	101	25.9
17	1965-1969	753	20.7	646	20.7	418	20.8	118	21.1
18	1970-1974	53	17.9	36	17.8	21	18.0	5	18.0

Controlling for age-related changes was more complicated. Many dimensions of the adult body change as a person ages (Trotter and Gleser, 1951a; Baer, 1956; Hertzog, et al., 1969; Damon, et al., 1972; Himes and Mueller, 1977; Borkan, et al., 1983; Chumlea et al., 1988; Cline, et al., 1989). Typically, the adolescent growth spurt is followed by a long period of little or no change, which is followed by a period of more rapid changes associated with senescent decline (see Figure 2). The actual pattern and magnitude of these changes will vary for different anthropometric dimensions. The Army population, however, is comprised of men ranging from 17 to about 50 years of age. Therefore, age-related changes need only be examined within this range. Because this age range is not associated with rapid growth or decline, age related changes can be modelled as a straight line.

The cohorts used in this analysis vary by both age and birth year, i.e., the same cohort drawn from the two survey data bases will represent different age groups. Therefore, the relationship between dimension and cohort is influenced by both age and secular changes. A plot of chest circumference versus cohort (see Figure 3) best illustrates this pattern. This example, and Table 1, show that the two surveys overlap by four cohorts. Because a cohort represents persons born in a specific interval of years, the observed difference in values between a cohort in 1966 and the same cohort in 1988, represented by points A and B in Figure 2, must be because of age at the time of measurement. This difference can be read as the change due to age in a 22 year period. Multiplying this value by 5/22 converts it into the rate of age related change per five year cohort. This creates a two point linear model of age related change. As many as twenty such models, one for each birth-year in the four overlapping cohorts, were generated in this fashion for each anthropometric dimension in each racial/cultural group. The inherent weakness of a two-point linear model was addressed by using the mean value of the slopes of these models, for each dimension within a racial/cultural group, as the best estimate of the rate of change due to aging (Hyde, 1980). Rates of age-related change calculated in this fashion are comparable to previously reported values (Cline et al., 1989).

Mean rates of age-related change were used to factor out the effects of age within each cohort. An age was chosen to represent the age of standard expression for anthropometric dimensions. Deviations from this age were then adjusted to control for age related effects (Relethford and Lees, 1981; Borkan, et al., 1983). Assuming that anthropometric dimensions reach their maximum, or mature, value at age 20[1], age adjusted values were calculated for each dimension according to the following equation:

$$AAV = V - AF\ (((Y - 1900)/5) - C). \qquad (1)$$

In this equation AAV is the Age Adjusted Value; V is the observed anthropometric Value; AF is the Age correction Factor; Y is the survey Year rounded down to 5 year intervals; and C is the birth year Cohort. The term (Y-1900)/5 works out to the age cohort that would include 20 year olds for the year Y. Figure 4, which is a plot of age adjusted values for chest circumference versus cohort, shows the results of this transformation.

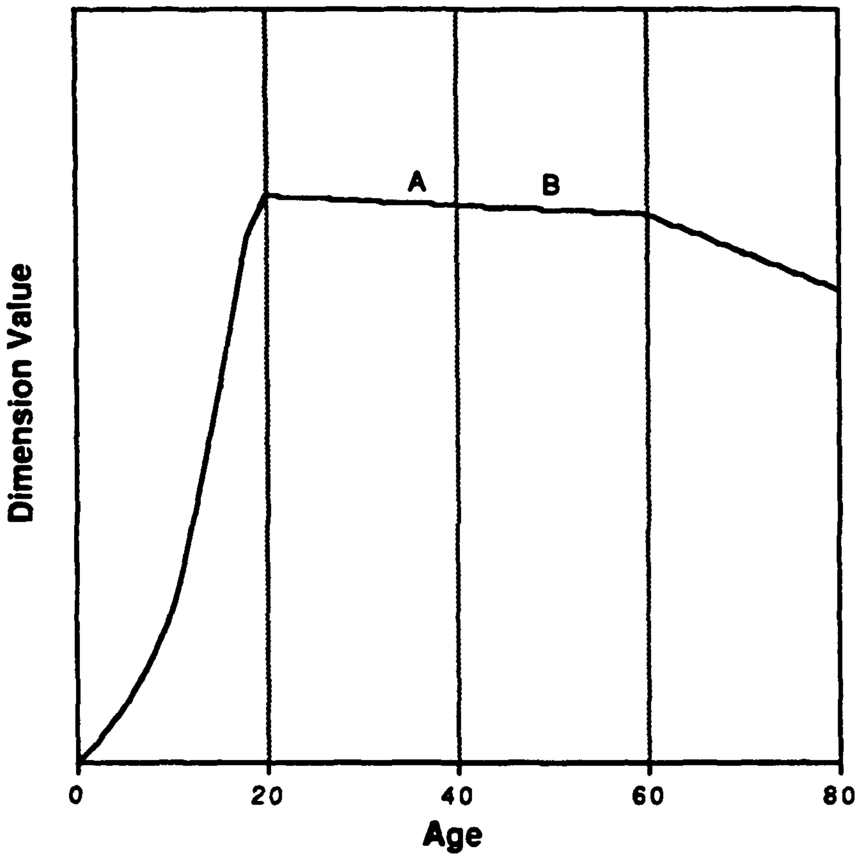

Figure 2. Changes associated with age typical of most anthropometric dimensions. See text for further discussion.

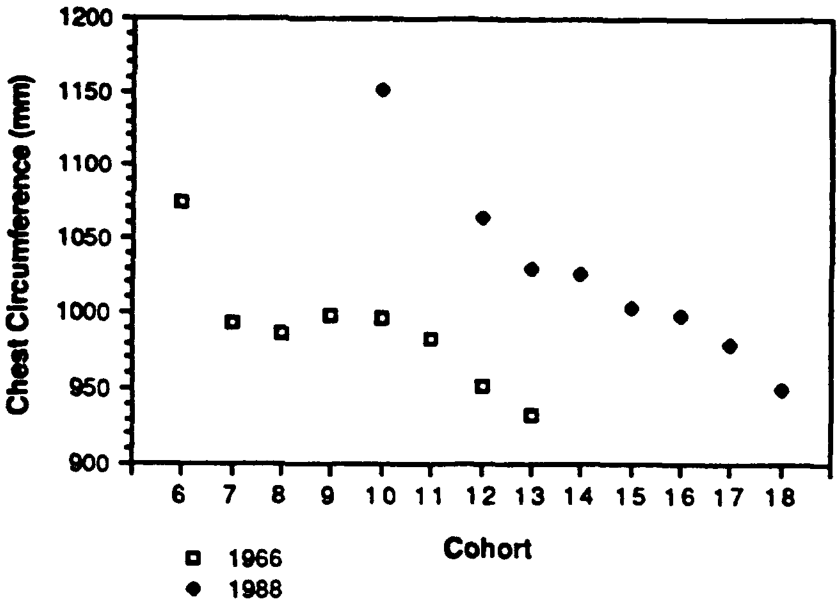

Figure 3. Plot of Chest Circumference vs. Birth Year Cohort for Whites

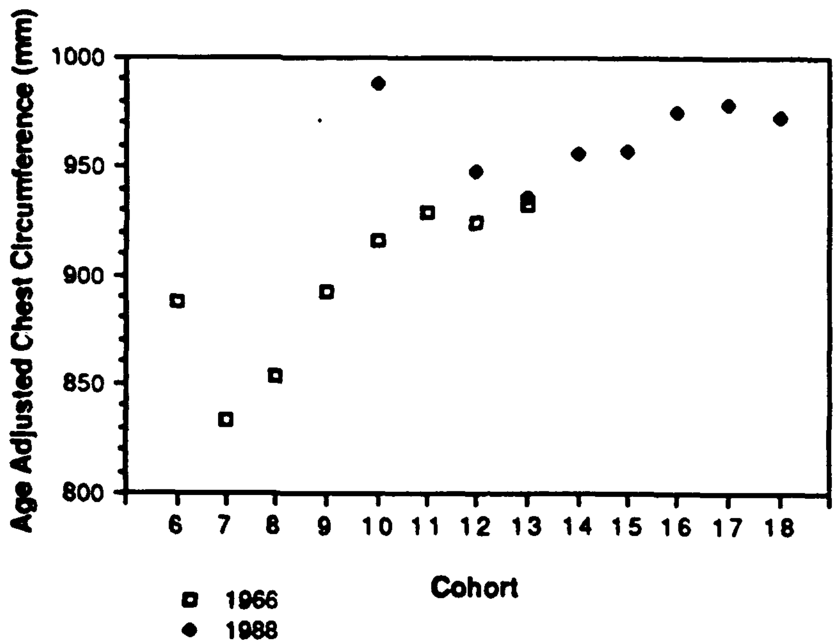

Figure 4. Plot of Age Adjusted Chest Circumference vs. Birth Year Cohort for Whites

Presumably the remaining minor differences between two age adjusted values for the same cohort are the results of uncontrollable sampling and observer error.

Secular trends were studied by regressing the age adjusted dimensions with cohort. These bivariate regressions produce the following generic equation:

$$AAV = a\ C + b. \tag{2}$$

In this linear equation b is the y-intercept constant and a is the slope of the line. Because this equation describes the relationship between cohort (time) and an anthropometric dimension, controlled for non-secular influences, the term a is the rate of secular change.

This linear equation was made into a predictive model by combining it with equation one and solving the relationship for V, the original anthropometric value, as follows:

$$V - AF\ (((Y - 1900)/5) - C) = a\ C + b. \tag{3}$$

Adding the term AF $(((Y - 1900)/5) - C)$ to both sides of the equation produces:

$$V = a\ C + b + AF\ (((Y - 1900)/5) - C). \tag{4}$$

Simplifying the equation:

$$V = a\ C + b + AF\ (Y - 1900)/5 - AF\ C \tag{5}$$

$$V = (a - AF)\ C + (b + AF\ (Y - 1900)/5) \tag{6}$$

For a given year the terms $b + AF\ (Y - 1900)/5$ and $(a - AF)$ will be constant. Therefore, equation six is a linear model that predicts V, where $b + AF\ (Y - 1900)/5$ is the y-intercept and $(a - AF)$ is the slope. Because this equation is equivalent to Equation 2 it can be described by the same regression statistics. Thus, F tests, corrected for 22 simultaneous comparisons, were used to evaluate the significance of the regression slope. In addition, the standard error of the estimate (SEE) values calculated for equation two were used to rate the confidence of predicted values.

Rates of secular change were compared between racial/cultural groups by testing equality of regression slopes with analysis of covariance software. Slope comparisons with low F values and significance levels greater than 0.05, corrected for 11 simultaneous comparisons, were not considered to be statistically different. This information was used to determine which groups were undergoing markedly different trends for specific dimensions.

Discriminant analysis was then used to determine which dimensions were undergoing the most change relative to the other body dimensions. This analysis was conducted by using the age adjusted dimensions to discriminate between the 1966 and 1988 survey populations. Those dimensions that showed the highest within-group correlations were identified as having changed the most. Patterns of change were then compared by repeating this analysis for each racial/cultural group.

3. RESULTS AND DISCUSSION

The relationships between birth year cohort and the anthropometric dimensions are presented as Appendix I (Figures 6 through 27). Table 3 lists the secular trends rates revealed by these relationships. The rate of secular change for the stature of Whites estimated here (3.71 mm per cohort or 0.7 cm per decade) is comparable to the commonly reported rate of 0.6 cm per decade (Bradtmiller et al., 1985; Annis, 1978). Several trends described in Table 3, all associated with Asians/Pacific Islanders, are not significantly different from zero. This lack of relationship implies that these dimensions are not undergoing significant secular trends. Visual inspection of the plots of some dimensions also suggest that, although significant slopes were observed, these rates of change may be decreasing. In these dimensions secular change may no longer be occurring, or is occurring at a greatly reduced rate. Dimensions with these patterns are: in Whites — calf height, crotch height, head breadth, bizygomatic breadth, and hand breadth; in Blacks — calf height forearm-hand length, head length, head breadth, bizygomatic breadth, foot length, hand length, and hand breadth; in Hispanics — neck circumference, crotch height, sitting height, head breadth, bizygomatic breadth, and hand breadth; and in Asians/Pacific Islanders — weight, sitting height, forearm-hand length, knee height sitting, head breadth, bizygomatic breadth, hand length, and hand breadth. All dimensions were explored using non-linear regression techniques. In no instance, however, were models markedly improved, as judged by correlations and standard errors. Therefore linear models were retained for all dimensions.

Comparisons of secular change rates are presented in Figure 5. Tests for the equality of slopes showed that all groups had significantly different rates of secular change ($p<.05$), with the following exceptions: Blacks, Hispanics and Asians/Pacific Islanders showed no significant differences in the rate of change for head breadth. Blacks and Asians/Pacific Islanders showed no significant differences in rates for five dimensions: neck circumference, bideltoid breadth, thumbtip reach, head length, and hand length. Blacks and Hispanics showed no significant differences in rates for two dimensions: calf height and bizygomatic breadth. Whites and Hispanics showed no significant differences in rates for three dimensions: chest circumference, bideltoid breadth, and hand breadth. In addition, Whites and Hispanics showed very similar rates of change in 14 more dimensions.

Table 4 shows the results of the discriminant analyses. Those dimensions with the highest within-group correlation to the discriminant function show the greatest amounts of change between the survey years. Therefore, those dimensions were judged to have undergone the most secular change. The analysis was first used to test the entire sample of pooled races to determine the baseline pattern of change for the entire population. In the test of pooled races the measurements related to soft tissue (i.e., muscle and fat) were most highly correlated with discrimination; whereas skeletal dimensions, such as stature and head breadth, were poorly correlated with discrimination. This

TABLE 3.
Secular Trend Rates Within Racial/Cultural Groups

Dimension	Whites	Blacks	Hispanics	Asians
Weight	1.36	0.77	1.44	-0.13†
Stature	3.71	1.46	5.34	-5.64
Neck Circumference	0.59	-0.66	0.22	-0.72
Chest Circumference	10.78	7.48	10.74	2.26
Calf Height	-0.27	-0.76	-0.70	-1.53
Calf Circumference	2.67	1.69	2.51	0.83
Crotch Height	0.46	0.44	-0.26	-3.88
Sitting Height	3.57	3.21	4.27	-0.42
Forearm-Hand Length	0.99	-0.22	1.27	-0.51
Knee Height, Sitting	4.68	3.55	4.09	-0.06†
Bideltoid Breadth	8.54	6.63	8.39	6.27
Chest Breadth	3.78	0.97	4.63	1.43
Hip Breadth, Sitting	5.41	4.77	6.37	3.46
Thumbtip Reach	-6.53	-8.34	-5.29	-8.11
Head Length	0.51	0.03	0.79	0.89
Head Circumference	0.52	0.54	1.69	2.11
Head Breadth	-0.25	-0.17	-0.18	-0.14
Bizygomatic Breadth	-0.09	-0.05	-0.05	0.05†
Ankle Circumference	-0.71	-1.28	-0.81	-2.67
Foot Length	0.71	-0.06	0.82	-0.92
Hand Length	0.98	0.40	0.91	0.44
Hand Breadth	0.46	0.25	0.44	-0.09

Values are presented in millimeters per cohort, which can be read as millimeters change per five years. Data on weight are presented in kilograms per cohort. Trends marked with a dagger (†) are not significantly different from zero at the .05 level.

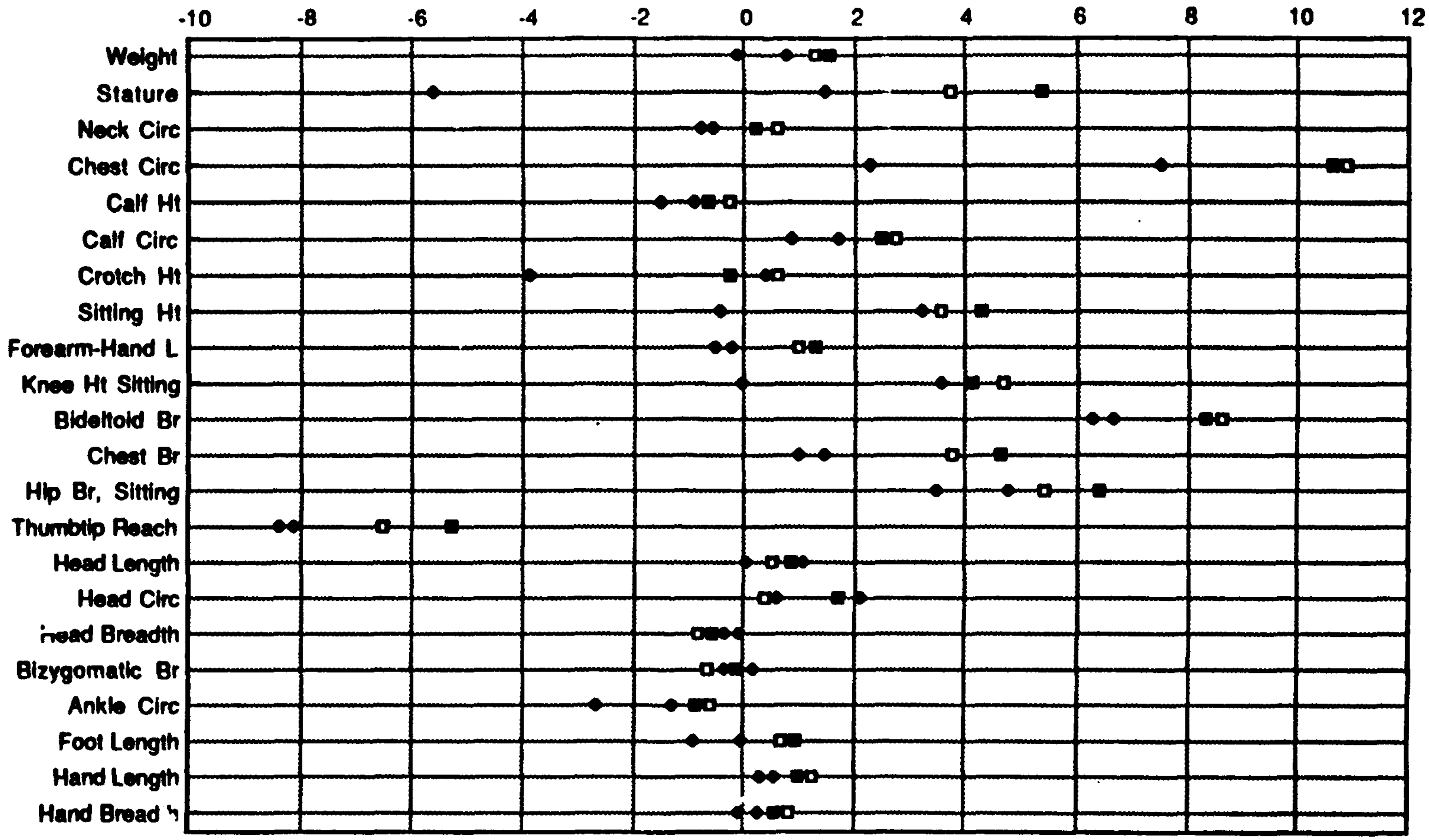

Figure 5. Comparison of Trends Among the Racial/Cultural Groups

TABLE 4.
1966 vs. 1988
Pooled Within-Groups Correlations Between Measurements and Discriminant Functions

POOLED RACES			
Bideltoid Breadth	-0.451	Head Length	-0.105
Hip Breadth	-0.296	Hand Breadth	-0.090
Knee Height, Sitting	-0.226	Foot Length	-0.077
Chest Circumference	-0.212	Forearm-Hand Length	-0.076
Chest Breadth	-0.192	Head Breadth	-0.068
Thumbtip Reach	-0.189	Neck Circumference	-0.065
Weight	-0.172	Sitting Height	-0.056
Hand Length	-0.139	Stature	-0.054
Calf Circumference	-0.121	Crotch Height	-0.022
Ankle Circumference	0.118	Calf Height	-0.021
Head Circumference	-0.107	Bizygomatic Breadth	-0.006

WHITES			
Bideltoid Breadth	0.458	Sitting Height	0.111
Hip Breadth	0.320	Ankle Circumference	-0.104
Chest Breadth	0.231	Hand Breadth	0.090
Chest Circumference	0.227	Head Breadth	-0.080
Knee Height	0.221	Neck Circumference	0.070
Thumbtip Reach	-0.210	Stature	0.069
Weight	0.179	Foot Length	0.056
Calf Circumference	0.125	Forearm-Hand Length	0.050
Head Length	0.124	Bizygomatic Breadth	-0.012
Hand Length	0.124	Calf Height	-0.008
Head Circumference	0.112	Crotch Height	0.002

BLACKS			
Bideltoid Breadth	0.370	Hand Breadth	0.054
Hip Breadth	0.294	Hand Length	0.049
Thumbtip Reach	-0.216	Stature	0.046
Chest Circumference	0.192	Bizygomatic Breadth	0.046
Knee Height	0.171	Crotch Height	0.025
Sitting Height	0.141	Foot Length	0.024
Weight	0.137	Calf Height	-0.020
Chest Breadth	0.113	Forearm-Hand Length	0.010
Ankle Circumference	-0.106	Head Breadth	-0.008
Calf Circumference	0.106	Neck Circumference	0.008
Head Circumference	0.066	Head Length	0.003

TABLE 4.
(Continued)

1966 vs. 1988
Pooled Within-Groups Correlations Between Measurements and Discriminant Functions

HISPANICS			
Bideltoid Breadth	0.448	Sitting Height	0.095
Hip Breadth	0.327	Head Length	0.091
Chest Breadth	0.245	Foot Length	0.083
Chest Circumference	0.243	Forearm-Hand Length	0.075
Weight	0.208	Ankle Circumference	-0.072
Knee Height	0.188	Neck Circumference	0.069
Calf Circumference	0.164	Stature	0.061
Thumbtip Reach	-0.158	Bizygomatic Breadth	0.044
Head Circumference	0.118	Calf Height	-0.034
Hand Breadth	0.114	Head Breadth	-0.012
Hand Length	0.114	Crotch Height	0.012

ASIAN/PACIFIC ISLANDERS			
Bideltoid Breadth	-0.256	Head Breadth	0.068
Thumbtip Reach	0.211	Weight	-0.058
Ankle Circumference	0.173	Head Circumference	-0.042
Hip Breadth	-0.170	Sitting Height	0.036
Calf Height	0.122	Bizygomatic Breadth	0.028
Crotch Height	0.118	Head Length	-0.028
Chest Circumference	-0.105	Forearm-Hand Length	0.014
Hand Length	-0.092	Foot Length	-0.012
Stature	0.088	Neck Circumference	-0.009
Chest Breadth	-0.079	Knee Height	-0.003
Calf Circumference	-0.071	Hand Breadth	0.001

pattern was, for the most part, reflected in the results of separate discriminant analyses of each group. Because skeletal dimensions had the lowest correlation with discrimination the traditional explanations of increased health and nutrition cannot be invoked as important contributors to the observed secular trends. Instead, these patterns may reflect the influence of the recent cultural emphases on physical fitness and the "ideal" body, which could be expected to affect the muscle/fat dependent measurements more than the skeletal dimensions (Takahashi, 1986).

The sole exception to this discrimination pattern was the Asian/Pacific Islanders. The correlations of Asian/Pacific Islanders mirrored their general trend of decreasing anthropometric dimensions and suggested that cultural factors may not be the best explanation of change in this group. An explanation for this difference was found in the immigration patterns of the four groups.

Immigration patterns are presented in Table 5. These patterns were evaluated using a Mantel-Haenszel/Chi-Square test (Mantel, 1963) of the linear relationship between birthplace (USA vs. non-USA). Adjacent cohorts were sometimes pooled in these analyses to avoid sparse cells that would compromise the validity of the Mantel-Haenszel test. Cells were scored according to the median birth year of their membership. These tests showed no significant differences in the immigration pattern of Whites. Blacks and Hispanics both showed significant patterns of linear increase in the number of non-USA born members, but these groups are still primarily comprised of native born Americans. Therefore, the effects of immigration may not be strong enough to have had a large influence on their secular change patterns. Asians/Pacific Islanders also show significant differences in their immigration pattern. This difference was primarily because of a shift towards non-American born membership, with the Philippines as the modal birthplace. This suggests that migration is the primary influencing factor for the observed secular changes of Asians/Pacific Islanders.

4. APPLICATION

Tables 6 through 9 present the linear models generated in this analysis. These models may be used by substituting the values for the constant (b), secular trend (a) and age trend (AF) into Equation 6. This will provide a prediction of an anthropometric dimension (V) for a specific cohort in a particular year. Demographic information on age distributions should be used to weight the predicted value for each cohort to determine an average value for a particular year.

This method was developed to predict the anthropometric dimensions of a future Army population. Its use, however, can be illustrated by predicting average values for a previous US Army anthropometric survey. The results of the 1946 survey of US Army personnel (Newman and White, 1951) reports values of White men. Therefore, the models for White men reported in Table 6 can be used to predict dimensions of the 1946 Army that can be checked against the reported values.

TABLE 5
Evaluation of Immigration Patterns

WHITES: Observed/Expected Values

Birthplace	Median Birthyear 1930	1943	1946	1951	1956	1961	1967
USA	204 198.1	832 838.6	1318 1315.8	164 165.2	228 232.8	388 392.2	770 761.3
Non-USA	1 7.0	36 29.4	44 46.2	7 5.8	13 8.2	18 13.8	18 26.7

Mantel-Haenszel Chi Square = 0.008 d.f. = 1 p. = .931

BLACKS: Observed/Expected Values

Birthplace	Median Birthyear 1941	1946	1955	1961	1967
USA	378 370.8	443 436.2	387 393.4	344 347.4	661 665.5
Non-USA	2 9.2	4 10.8	16 9.8	12 8.6	21 16.5

Mantel-Haenszel Chi Square = 10.660 d.f. = 1 p = .001

HISPANICS: Observed/Expected Values

Birthplace	Median Birthyear 1943	1946	1952	1956	1961	1966
USA	56 84.0	88 91.3	61 67.2	86 102.5	141 144.0	303 245.9
Non-USA	94 66.0	75 71.7	59 52.8	97 80.5	116 113.0	136 193.1

Mantel-Haenszel Chi Square = 42.231 d.f. = 1 p = .000

ASIANS: Observed/Expected Values

Birthplace	Median Birthyear 1942	1946	1952	1957	1961	1966
USA	16 8.1	21 15.2	14 17.6	12 22.3	22 24.7	33 30.1
Non-USA	17 24.9	41 46.8	58 54.4	79 68.7	79 76.3	90 92.9

Mantel-Haenszel Chi Square = 4.270 d.f. = 1 p = .039

TABLE 6
Models for Whites

Dimension	Constant	Secular Trend	Age Factor	SEE	R	Sig.
	b	a	AF			
Weight	53.55	1.36	2.85	0.74	.94	.000
Stature	1700	3.71	3.54	5.11	.72	.000
Neck Circ.	365.9	0.59	2.86	2.50	.21	.000
Chest Circ.	796.3	10.78	23.25	6.00	.94	.000
Calf Height	354.4	-0.27	-0.68	1.57	.12	.000
Calf Circ.	331.8	2.67	4.35	2.41	.86	.000
Crotch Height	829.3	0.46	-1.12	4.21	.05	.000
Sitting Height	863.6	3.57	5.14	3.50	.83	.000
Forearm-Hand Length	463.1	0.99	1.46	1.88	.57	.000
Knee Height Sitting	478.2	4.68	4.35	2.07	.96	.000
Bideltoid Breadth	343.5	8.54	9.41	3.77	.96	.000
Chest Breadth	254.9	3.78	7.79	2.01	.94	.000
Hip Breadth Sitting	273.1	5.41	8.01	1.94	.97	.000
Thumbtip Reach	905.8	-6.53	-2.71	4.98	.89	.000
Head Length	188.6	0.51	0.43	0.96	.57	.000
Head Circ.	557.5	0.52	-0.02	3.42	.10	.000
Head Breadth	154.8	-0.25	0.77	0.79	.32	.000
Bizygomatic Breadth	140.2	-0.09	0.91	0.09	.09	.000
Ankle Circ.	235.4	-0.71	0.04	1.98	.38	.000
Foot Length	256.0	0.71	1.19	0.99	.71	.000
Hand Length	175.3	0.98	1.51	0.80	.88	.000
Hand Breadth	82.53	0.46	0.89	0.66	.69	.000

TABLE 7
Models for Blacks

Dimension	Constant	Secular Trend	Age Factor	SEE	R	Sig.
	b	a	AF			
Weight	63.56	0.77	2.11	1.74	.48	.000
Stature	1732	1.46	-1.19	5.86	.23	.000
Neck Circ.	389.4	-0.66	0.87	3.24	.17	.000
Chest Circ.	835.1	7.48	18.89	9.68	.74	.000
Calf Height	382.8	-0.76	-2.20	2.87	.25	.000
Calf Circ.	347.2	1.69	2.80	3.30	.57	.000
Crotch Height	855.7	0.44	-4.77	4.10	.05	.000
Sitting Height	835.6	3.21	2.39	3.54	.80	.000
Forearm-Hand Length	502.6	-0.22	-0.18	1.79	.07	.000
Knee Height Sitting	509.6	3.55	2.87	2.30	.92	.000
Bideltoid Breadth	376.4	6.63	7.71	5.63	.87	.000
Chest Breadth	290.7	0.97	4.58	3.65	.25	.000
Hip Breadth Sitting	274.9	4.77	6.98	4.83	.82	.000
Thumbtip Reach	959.6	-8.34	-7.89	3.46	.97	.000
Head Length	196.7	0.03	0.53	0.51	.02	000
Head Circ.	557.3	0.54	2.36	1.38	.42	.000
Head Breadth	153.4	-0.17	0.41	0.56	.30	.000
Bizygomatic Breadth	141.1	-0.05	0.56	0.84	.02	.000
Ankle Circ.	241.1	-1.28	-0.76	1.38	.80	.000
Foot Length	275.0	0.06	-0.10	1.04	.01	.000
Hand Length	192.0	0.40	1.16	0.71	.60	.000
Hand Breadth	86.34	0.25	0.84	0.45	.61	.000

TABLE 8
Models for Hispanics

Dimension	Constant	Secular Trend	Age Factor	SEE	R	Sig.
	b	a	AF			
Weight	49.50	1.44	2.29	1.32	.82	.000
Stature	1622	5.34	2.77	7.60	.65	.000
Neck Circ.	369.0	0.22	2.06	2.90	.02	.000
Chest Circ.	792.4	10.74	20.57	8.66	.85	.000
Calf Height	357.3	-0.70	-2.58	2.66	.21	.000
Calf Circ.	329.7	2.51	1.83	3.95	.60	.000
Crotch Height	816.0	-0.26	-5.84	3.90	.02	.000
Sitting Height	823.8	4.27	4.91	5.07	.85	.000
Forearm-Hand Length	450.1	1.27	0.05	2.70	.45	.000
Knee Height Sitting	475.3	4.09	2.46	2.60	.90	.000
Bideltoid Breadth	344.0	8.39	8.87	3.88	.95	.000
Chest Breadth	239.2	4.63	8.42	2.51	.93	.000
Hip Breadth Sitting	252.4	6.37	8.38	2.47	.96	.000
Thumbtip Reach	869.9	-5.29	-5.80	4.74	.82	.000
Head Length	180.2	0.79	0.75	0.79	.79	.000
Head Circ.	533.9	1.69	2.56	1.32	.86	.000
Head Breadth	155.1	-0.18	0.54	0.51	.32	.000
Bizygomatic Breadth	141.6	-0.05	0.53	0.77	.02	.000
Ankle Circ.	232.6	-0.81	-1.52	1.28	.60	.000
Foot Length	251.1	0.82	-0.02	1.35	.58	.000
Hand Length	173.2	0.91	0.97	1.03	.75	.000
Hand Breadth	80.84	0.44	0.56	0.43	.80	.000

TABLE 9
Models for Asian/Pacific Islanders

Dimension	Constant	Secular Trend	Age Factor	SEE	R	Sig.
	b	a	AF			
Weight	74.18	-0.13	0.43	1.95	.01	.011
Stature	1791	-5.64	-8.87	12.31	.38	.000
Neck Circ.	381.6	-0.72	1.07	3.47	.11	.000
Chest Circ.	907.5	2.26	8.36	11.46	.10	.000
Calf Height	355.1	-1.53	-2.13	4.58	.25	.000
Calf Circ.	366.4	0.83	1.36	4.34	.10	.000
Crotch Height	858.2	-3.88	-7.67	5.64	.58	.000
Sitting Height	908.4	-0.42	-0.43	7.14	.01	.000
Forearm-Hand Length	473.2	-0.51	-1.02	3.68	.05	.000
Knee Height Sitting	531.5	-0.06	-1.51	4.09	.00	.556
Bideltoid Breadth	378.3	6.27	6.04	4.07	.87	.000
Chest Breadth	283.5	1.43	4.29	3.84	.29	.000
Hip Breadth Sitting	295.7	3.46	5.54	4.50	.63	.000
Thumbtip Reach	902.5	-8.11	-8.04	3.79	.93	.000
Head Length	175.7	0.89	0.75	1.45	.52	.000
Head Circ.	524.8	2.11	2.82	3.75	.48	.000
Head Breadth	157.1	-0.14	0.49	1.04	.05	.000
Bizygomatic Breadth	143.7	0.05	0.77	0.90	.01	.023
Ankle Circ.	264.5	-2.67	-3.35	1.99	.84	.000
Foot Length	276.9	-0.92	-2.32	2.88	.23	.000
Hand Length	180.7	0.44	0.28	1.82	.15	.000
Hand Breadth	89.99	-0.09	-0.31	0.95	.02	.001

Demographic information from the 1946 survey provides the following distribution of birth-year cohorts: Cohort 10 at 0.399%, Cohort 9 at 47.3%, Cohort 8 at 20.8%, Cohort 7 at 24.8%, Cohort 6 at 5.5%, Cohort 5 at 0.879%, and Cohort 4 at 0.350%. Equation six can be used to predict the value of stature for cohort 10 in 1946, rounded down to 1945, as follows:

$$V = (a - AF)\ C + (b + AF\ (Y - 1900)/5)$$

substituting:

$$STATURE = (3.71 - 3.54) * 10 + (1700 + 3.54 *(1945 - 1900)/5)$$

which yields:

$$STATURE = 1733.72 \text{ mm.}$$

Following this procedure for cohorts nine to four produces:

Cohort	Proportion	Prediction	Weighted Value
10	.00399	1733.56	6.92
9	.473	1733.39	819.89
8	.208	1733.22	360.51
7	.248	1733.05	429.80
6	.055	1732.88	95.31
5	.00879	1732.71	15.23
4	.0035	1732.54	6.06

Adding the weighted values gives a prediction for stature in 1946 of 1734 mm. The standard error of the estimate for the Whites stature model of 5.11 mm plus an allowable observer error for stature of 10 mm (Clauser, et al., 1988) makes this prediction comparable to the 1739 mm reported for stature by Newman and White (1951). Table 10 compares predictions of available 1946 values to their actual values for the other dimensions. In part, some the variations between the actual and predicted values are due to different measuring techniques used in the 1946 survey. However, the greatest variations are seen in the soft tissue dimensions, such as bideltoid breadth. If, as hypothesized, these dimensions are more sensitive to cultural practices, then one would expect greater potential inaccuracy in the prediction of these dimensions.

Anthropometric dimensions of future Army populations would be predicted in a similar fashion. Population values, however, also have to consider the contribution of each of the racial/cultural groups. Therefore, these predictions must be supplied with information on the proportional representation of these groups in addition to the breakdown of cohorts within them. Thus, the precision of anthropometric predictions is dependent upon the accuracy of demographic information.

To illustrate, six projections for possible Army demographics in the year 2023 are presented in Tables 11 and 12. The mean value for an anthropometric

TABLE 10
Predicted Anthropometric Dimensions for 1946

Dimension	Predicted Value	Standard Error of the Estimate	Observer Error	Reported Values
Weight	67.2	0.74	0.3	70.2
Stature	1734	5.11	10	1739
Chest Circumference	905	6.00	15	924
Calf Circumference	357	2.41	5	358
Crotch Height	832	4.21	10	834
Sitting Height	897	3.50	6	909
Forearm-Hand Length	473	1.88	4	476
Knee Height, Sitting	520	2.07	2	549
Bideltoid Breadth	421	3.77	8	456
Chest Breadth	293	2.01	8	283
Hip Breadth, Sitting	324	1.94	6	354
Head Length	193	0.96	2	195
Head Circumference	562	3.42	5	567
Head Breadth	154	0.79	2	152
Bizygomatic Breadth	140	0.09	2	139
Ankle Circumference	230	1.98	4	227
Foot Length	263	0.99	3	265
Hand Length	185	0.80	3	193
Hand Breadth	87	0.66	2	87

Values are presented in millimeters, except for weight which is in kilograms.
Data on Observer Error are taken from Clauser, et al. (1988).

TABLE 11

Potential Changes in Future Populations as Compared to the 1988 Survey Demographics

Population Projection	Age Distribution	Racial/Cultural Group Distribution
A	No Change	No Change
B	No Change	Increased Minorities
C	Older Population	No Change
D	Older Population	Increased Minorities
E	Younger Population	No Change
F	Younger Population	Increased Minorities

TABLE 12
Demographic Breakdowns of Population Projections for the Year 2023

Population A

	Whites	Blacks	Hispanics	Asians
Proportion	0.6792	0.2553	0.0394	0.0162
Cohort	Proportions within Groups			
25	0.020	0.010	0.000	0.000
24	0.387	0.340	0.370	0.320
23	0.228	0.290	0.210	0.140
22	0.160	0.170	0.220	0.290
21	0.125	0.130	0.120	0.070
20	0.071	0.050	0.040	0.070
19	0.009	0.010	0.040	0.110
18	0.000	0.000	0.000	0.000

Population B

	Whites	Blacks	Hispanics	Asians
Proportion	0.550	0.300	0.100	0.050
Cohort	Proportions within Groups			
25	0.020	0.010	0.000	0.000
24	0.387	0.340	0.370	0.320
23	0.228	0.290	0.210	0.140
22	0.160	0.170	0.220	0.290
21	0.125	0.130	0.120	0.070
20	0.071	0.050	0.040	0.070
19	0.009	0.010	0.040	0.110
18	0.000	0.000	0.000	0.000

Population C

	Whites	Blacks	Hispanics	Asians
Proportion	0.6792	0.2553	0.0394	0.0162
Cohort	Proportions within Groups			
25	0.020	0.010	0.010	0.010
24	0.310	0.280	0.270	0.270
23	0.210	0.210	0.200	0.200
22	0.180	0.200	0.150	0.190
21	0.150	0.150	0.160	0.130
20	0.100	0.100	0.120	0.110
19	0.020	0.040	0.060	0.070
18	0.010	0.010	0.030	0.020

TABLE 12
Continued

Population D

	Whites	Blacks	Hispanics	Asians
Proportion	0.550	0.300	0.100	0.050
Cohort	Proportions within Groups			
25	0.020	0.010	0.010	0.010
24	0.310	0.280	0.270	0.270
23	0.210	0.210	0.200	0.200
22	0.180	0.200	0.150	0.190
21	0.150	0.150	0.160	0.130
20	0.100	0.100	0.120	0.110
19	0.020	0.040	0.060	0.070
18	0.010	0.010	0.030	0.020

Population E

	Whites	Blacks	Hispanics	Asians
Proportion	0.6792	0.2553	0.0394	0.0162
Cohort	Proportions within Groups			
25	0.400	0.400	0.380	0.420
24	0.320	0.310	0.350	0.270
23	0.180	0.160	0.150	0.100
22	0.050	0.080	0.090	0.060
21	0.030	0.030	0.010	0.060
20	0.010	0.010	0.010	0.090
19	0.007	0.010	0.010	0.000
18	0.003	0.000	0.000	0.000

Population F

	Whites	Blacks	Hispanics	Asians
Proportion	0.550	0.300	0.100	0.050
Cohort	Proportions within Groups			
25	0.400	0.400	0.380	0.420
24	0.320	0.310	0.350	0.270
23	0.180	0.160	0.150	0.100
22	0.050	0.080	0.090	0.060
21	0.030	0.030	0.010	0.060
20	0.010	0.010	0.010	0.090
19	0.007	0.010	0.010	0.000
18	0.003	0.000	0.000	0.000

dimension is then predicted as follows. First, separate predictions are calculated for each racial/cultural group, using the appropriate cohort proportions, according to the method outlined above. Then these four predictions are weighted according to their racial group proportions and summed. The resulting value is the predicted population mean value (source code for a computer program written in Turbo Pascal that calculates these predictions is provided in Appendix II). The resulting predictions for each of the six possible Army populations are presented in Table 13. When each prediction is compared to the 1988 survey values it is clear that the magnitude and direction of change is very dependent upon demographic factors.

As an alternative to the prediction of actual dimensions, the models presented here can also be used to predict when measurable change will occur for each dimension. Clauser, et al. (1988) provide information on the limitations of current measuring techniques in their table of "Allowable Observer Error." These error values can be applied to the secular change models as benchmarks for the amount of change that must occur before it can be reliably detected. The limitations of each model are statistically expressed by the standard error of the estimate (SEE). The SEE expresses the confidence of a prediction, and can be used to calculate the 95% confidence interval for each predicted value. By using the greater of the 95% confidence interval or the allowable observer error, it is possible to determine how much change must occur before it might reasonably be detectable. The rates of change established in the secular change models can then be used to show the amount of time needed to give rise to measurable change. Table 14 lists the amount of time, in years, for measurable change to occur for each dimension in each group.

5. MODEL LIMITATIONS

The models presented here incorporate several assumptions concerning the relationships among anthropometric dimensions, birth year, and age. It is important that the implications of these assumptions, and the limitations of a regression based statement, are understood before attempting to apply these models.

These regression models only predict values of populations means; they do not make any statement concerning the distribution about the mean. Typically designers are concerned with ranges of variation, so that items can accommodate the 5th through 95th percentile values of a certain dimension within the population. Unfortunately, no techniques exist that can be used to predict this sort of information. One should never assume that because the mean value has increased by 10 mm the 5th and 95th percentile values will have also increased by the same amount. This type of reasoning has no basis in the current understanding of biological change, and would constitute a serious misapplication of these models.

TABLE 13
Predicted Anthropometric Dimensions for the Year 2023

Dimension	Population Projection A	B	C	D	E	F	Reported 1988 Value
Weight	86.5	85.7	86.6	85.6	84.9	84.1	78.5
Stature	1778	1770	1769	1759	1779	1772	1756
Neck Circumference	400	429	399	428	398	427	380
Chest Circumference	1058	1052	1056	1050	1044	1039	991
Calf Height	351	350	348	347	352	351	353
Calf Circumference	395	394	394	392	393	392	378
Crotch Height	841	837	836	831	845	840	837
Sitting Height	939	934	934	929	938	933	914
Forearm-Hand Length	489	488	487	485	489	488	484
Knee Height, Sitting	589	586	586	582	590	587	559
Bideltoid Breadth	546	544	543	541	545	543	492
Chest Breadth	342	340	341	340	337	336	322
Hip Breadth, Sitting	402	401	401	399	399	398	367
Thumbtip Reach	754	752	751	748	751	750	801
Head Length	200	200	199	198	200	199	197
Head Circumference	571	571	567	568	570	571	568
Head Breadth	150	150	150	149	149	149	152
Bizygomatic Breadth	140	140	139	140	139	139	141
Ankle Circumference	216	215	216	214	216	215	222
Foot Length	274	273	272	271	274	273	270
Hand Length	200	200	199	199	199	199	194
Hand Breadth	94	93	93	93	93	93	90

Values are presented in millimeters, except for Weight which is presented in kilograms. Reported 1988 values taken from Gordon, et al. (1989).

Population A: Demographics identical to the 1988 survey.
Population B: Greater Representation of Minority Racial/Cultural Groups, No Change in Age Distribution.
Population C: Older Age Distributions, No Change in Racial/Cultural Group Distribution.
Population D. Older Age Distributions, And Greater Representation of Minority Racial/Cultural Groups.
Population E: Younger Age Distributions, No Change in Racial/Cultural Group Distribution.
Population F: Younger Age Distributions, And Greater Representation of Minority Racial/Cultural Groups.

TABLE 14
Predicted Time, in Years, for Measurable Change to Occur

Dimension	Whites	Blacks	Hispanics	Asians
Weight	10	25	10	150
Stature	15	25	15	25
Neck Circumference	55	50	140	50
Chest Circumference	10	15	10	50
Calf Height	60	40	40	30
Calf Circumference	10	20	20	55
Crotch Height	110	115	195	15
Sitting Height	10	15	15	170
Forearm-Hand Length	25	95	25	75
Knee Height, Sitting	5	10	10	670
Bideltoid Breadth	5	10	5	10
Chest Breadth	15	45	10	30
Hip Breadth, Sitting	10	10	5	15
Thumbtip Reach	20	15	20	15
Head Length	20	335	15	20
Head Circumference	65	50	15	20
Head Breadth	45	60	60	75
Bizygomatic Breadth	115	205	205	205
Ankle Circumference	30	20	25	10
Foot Length	25	255	20	35
Hand Length	20	40	20	45
Hand Breadth	25	45	25	115

One of the main assumptions incorporated in these models is linearity. Each model of secular change, and the age factors used within them, are built on the assumption that anthropometric dimensions follow a simple linear relationship with time. The typical growth curve, illustrated in Figure 2, clearly shows that this relationship is not true with regard to aging. Linear models can be justified only as the best descriptions of a small portion of a much grander pattern of change. Therefore, the assumption can only be justified for relatively short term projections. The further in time one deviates from the data used to build these models the greater the inaccuracy of these models.

The utility of secular trend models in predicting future body dimensions is dependent upon the assumption that the patterns of past trends will continue. This assumption is false. Observed trends cannot continue indefinitely. Biological influences on secular change, such as improved health and nutrition, have limited effect as genetic potential is reached. In addition, cultural influences are mercurial and can be expected to alter the tempo and direction of observed trends without warning. These models are only useful in the short term, as a best guess of what will happen tomorrow. Therefore, they should be applied with extreme caution. A suggested rule of thumb is to view those dimensions that require more than 20 years -- one generation -- for detectable change as undergoing no change at all. For these dimensions, the best prediction for future Army populations will remain those values reported in the most recent Army anthropometric survey.

6. ENDNOTE

1. The age of 20 was chosen for two reasons. First, as the Army is composed primarily of young people, the cohort that contains 20 year olds will tend to be the most, or second most, populous cohort. Therefore, this cohort was selected as the most "typical." Second, previous studies (Trotter and Glesser, 1951a; 1951b; Borkan, et al. 1983) show an increasing maturation rate within the US population, which has been used as an explanation of some observed secular changes. Because of this, some studies have chosen the age of 30 to represent the age of maximum growth (Trotter and Glesser, 1951a; Relethford and Lees, 1981; McCullough, 1982). These studies, however, were not investigating modern American populations. Current populations are obtaining maximum growth at a much younger age (Annis, 1978; Bradtmiller, et al. 1985). If this trend continues, then maximum growth would be reached at even younger ages in future populations. Therefore, it is appropriate to choose the age of 20 as the age of maximum growth.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-91/006 in the series of reports approved for publication.

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8. APPENDIX I

Plots of Secular Change in the Four Racial/Cultural Groups

Comparing the magnitude and direction of secular change among the four racial/cultural groups.

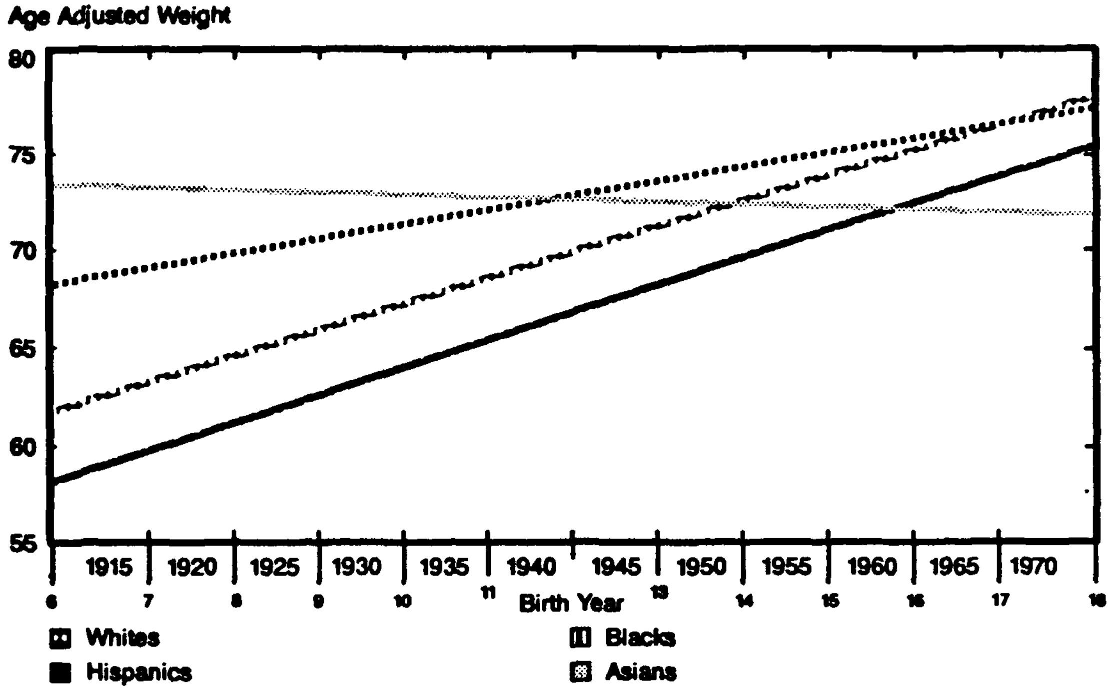

Figure 6. Secular Change of Weight

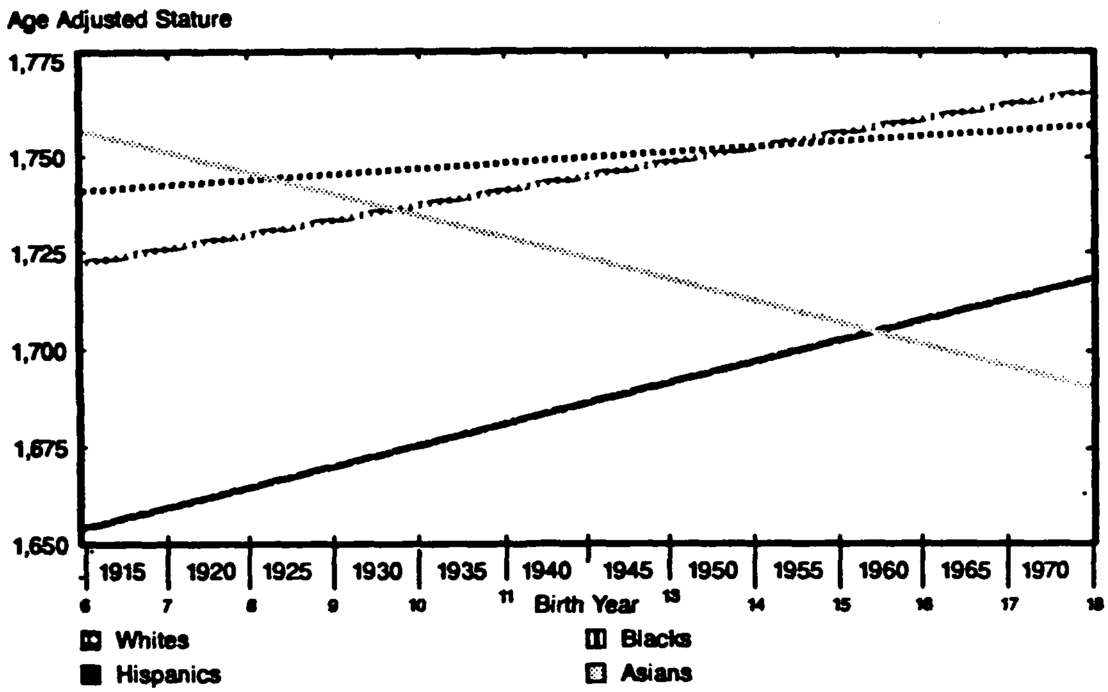

Figure 7. Secular Change of Stature

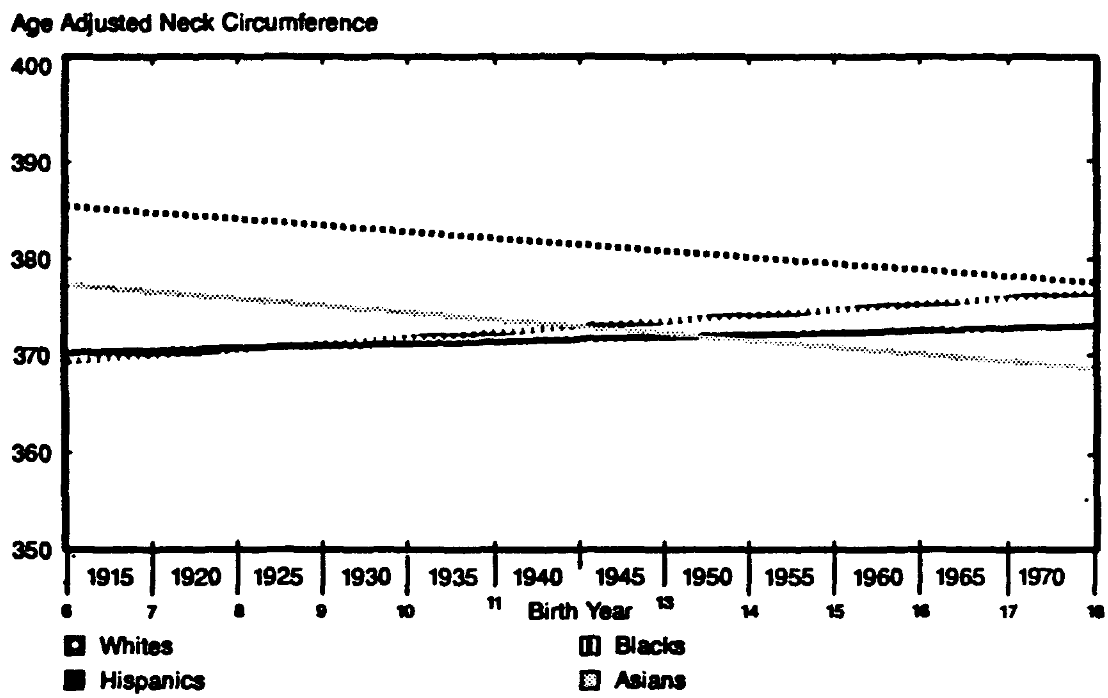

Figure 8. Secular Change of Neck Circumference

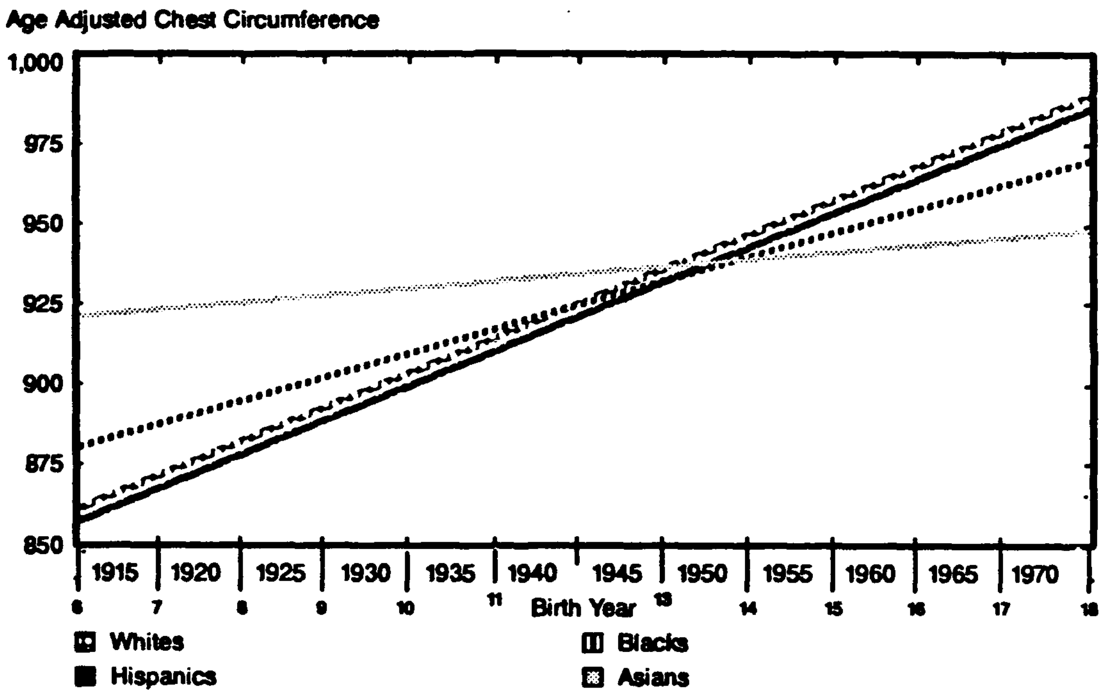

Figure 9. Secular Change of Chest Circumference

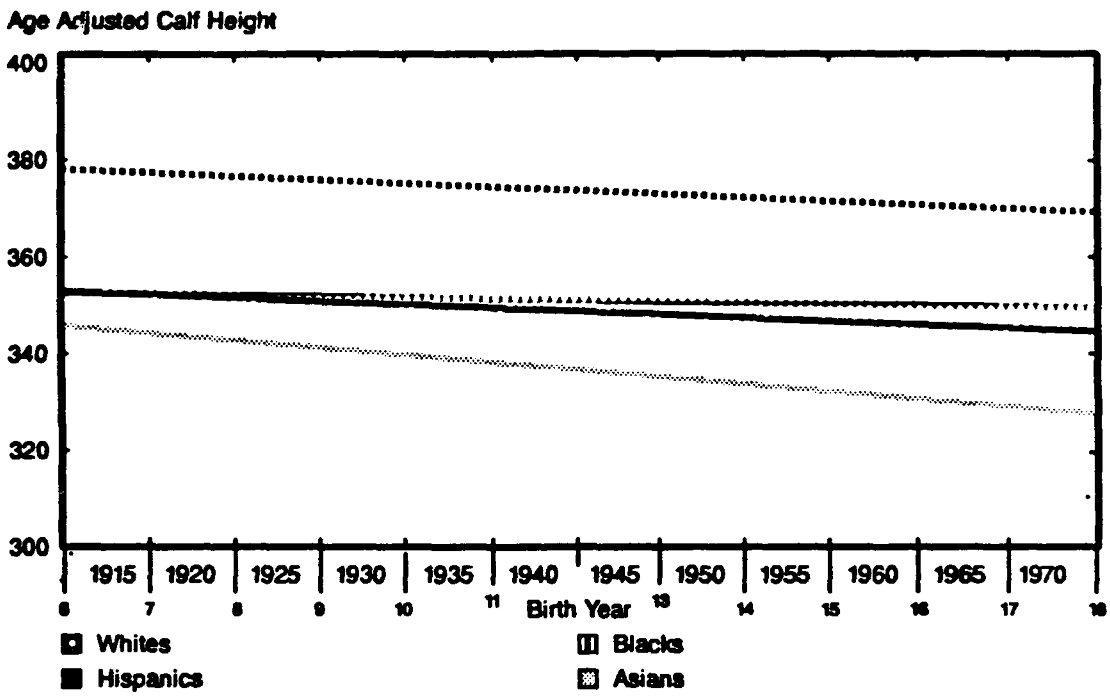

Figure 10. Secular Change of Calf Height

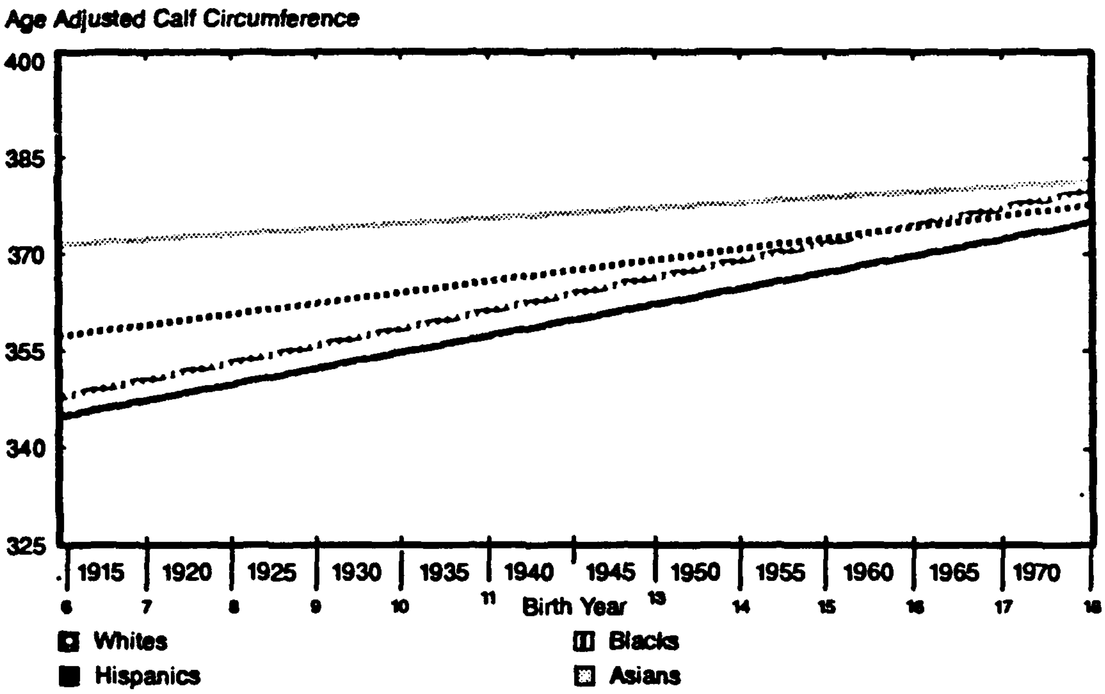

Figure 11. Secular Change of Calf Circumference

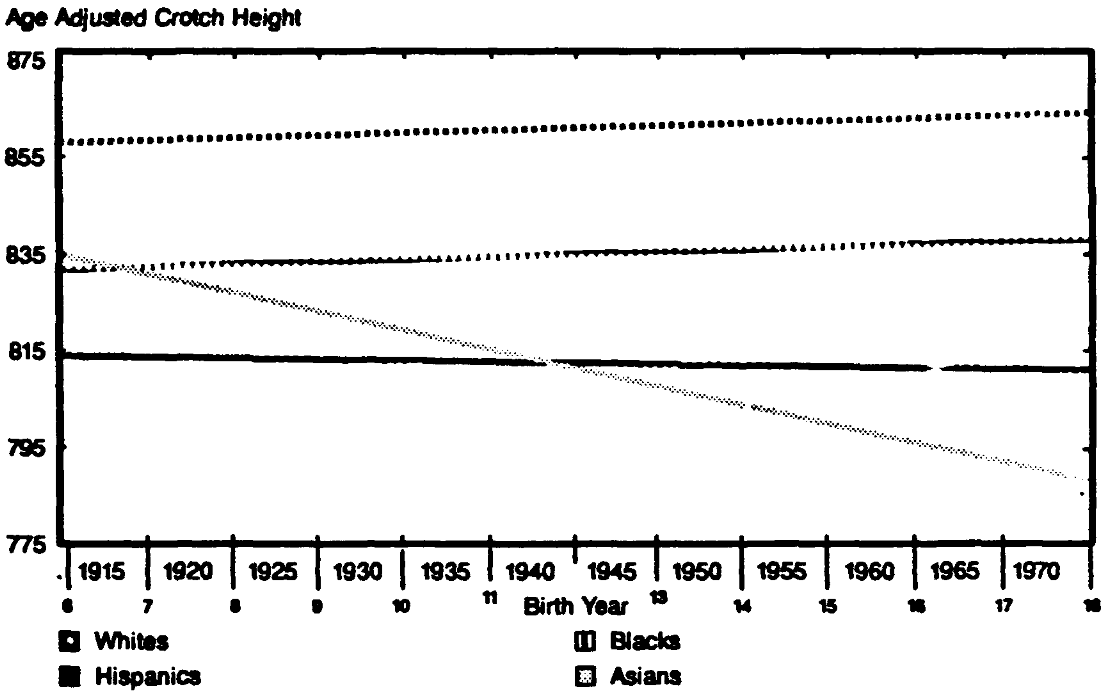

Figure 12. Secular Change of Crotch Height

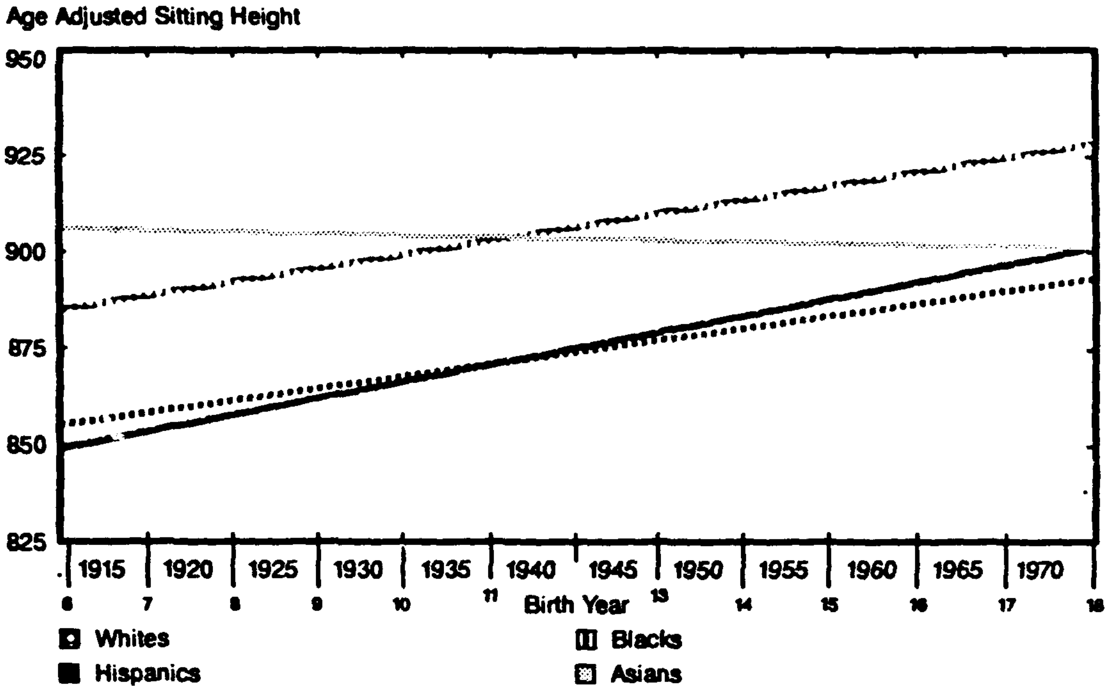

Figure 13. Secular Change of Sitting Height

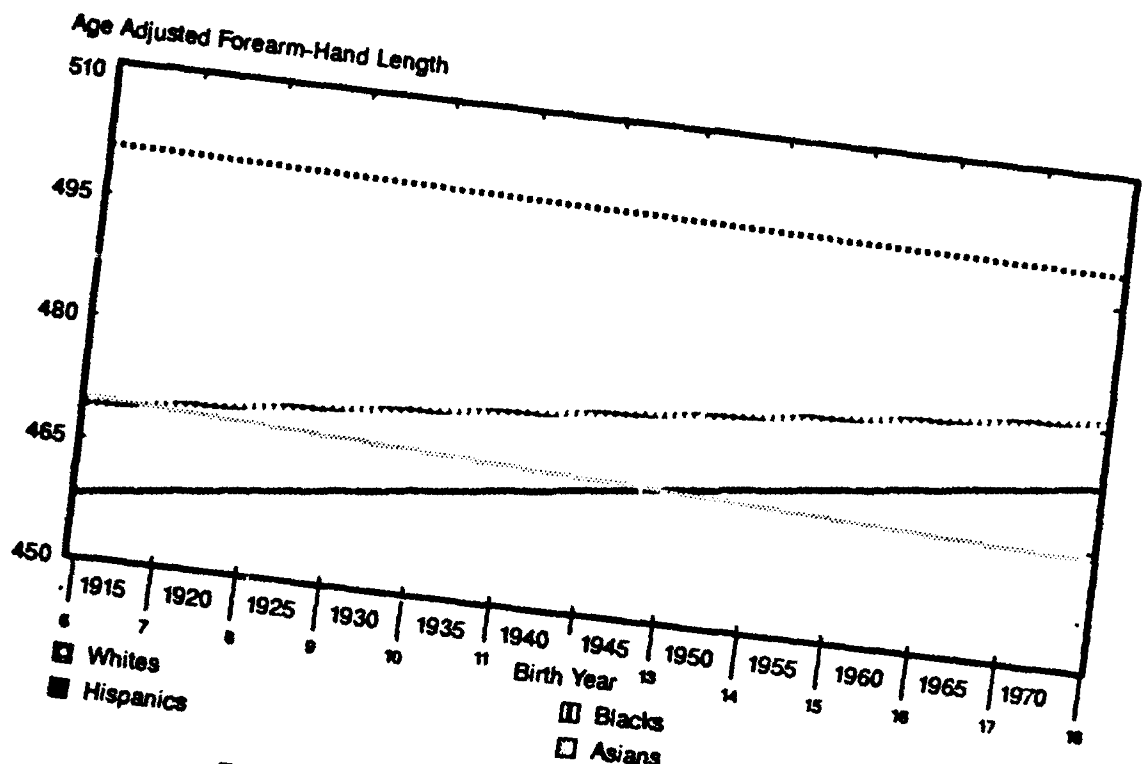

Figure 14. Secular Change of Forearm-Hand Length

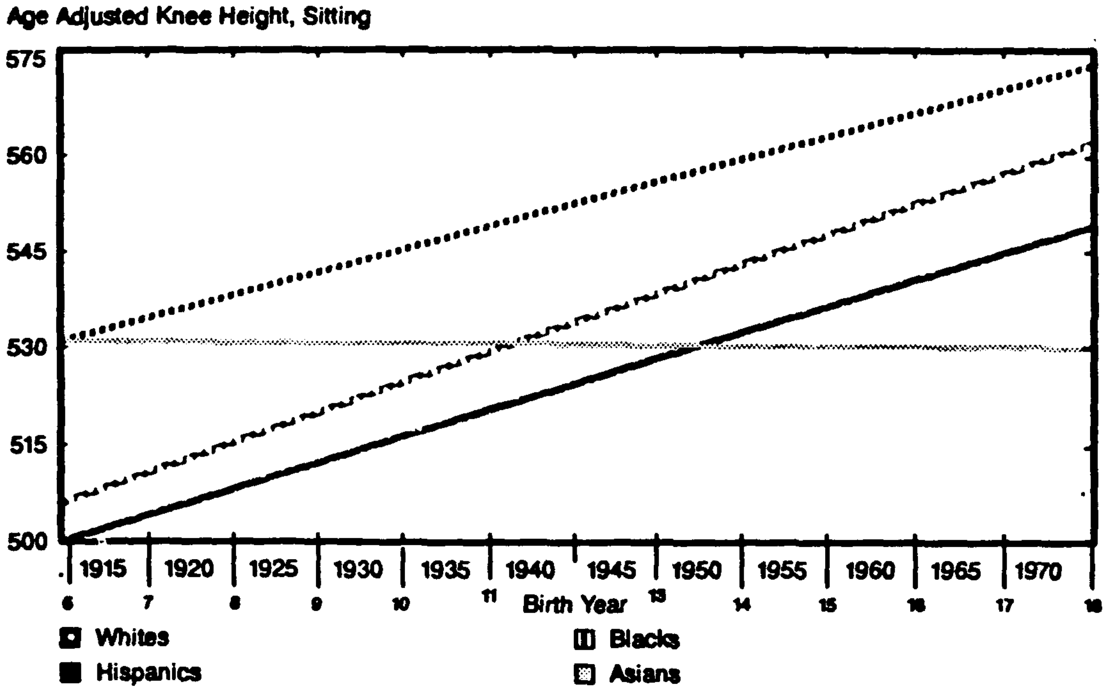

Figure 15. Secular Change of Knee Height, Sitting

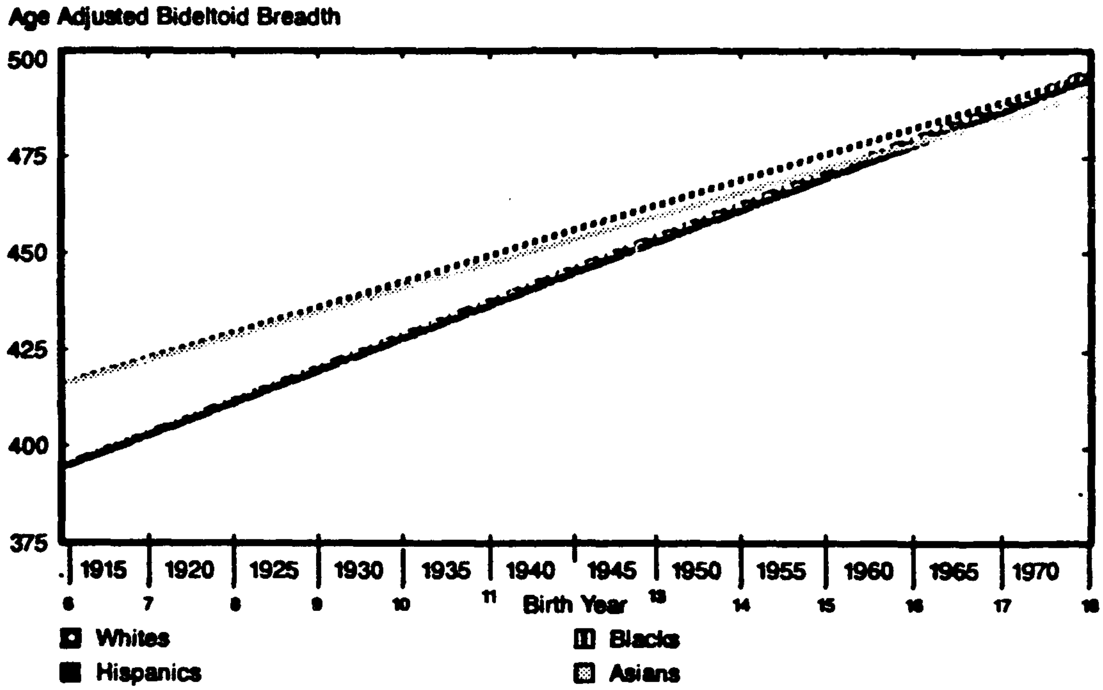

Figure 16. Secular Change of Bideltoid Breadth

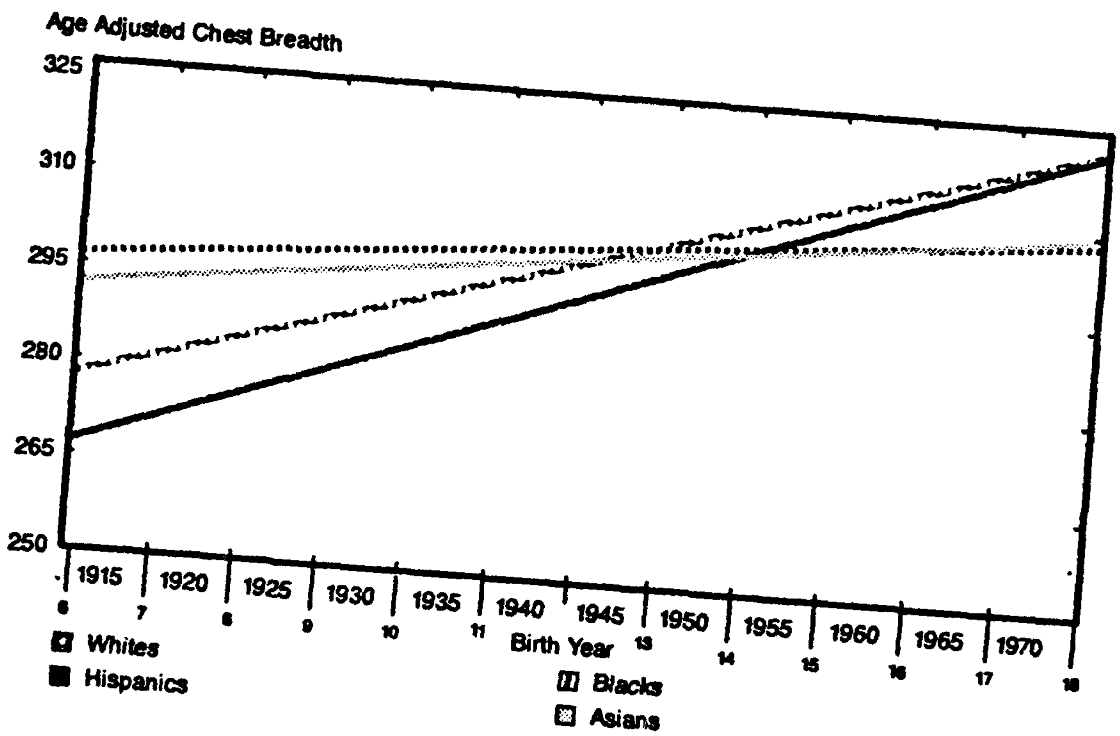

Figure 17. Secular Change of Chest Breadth

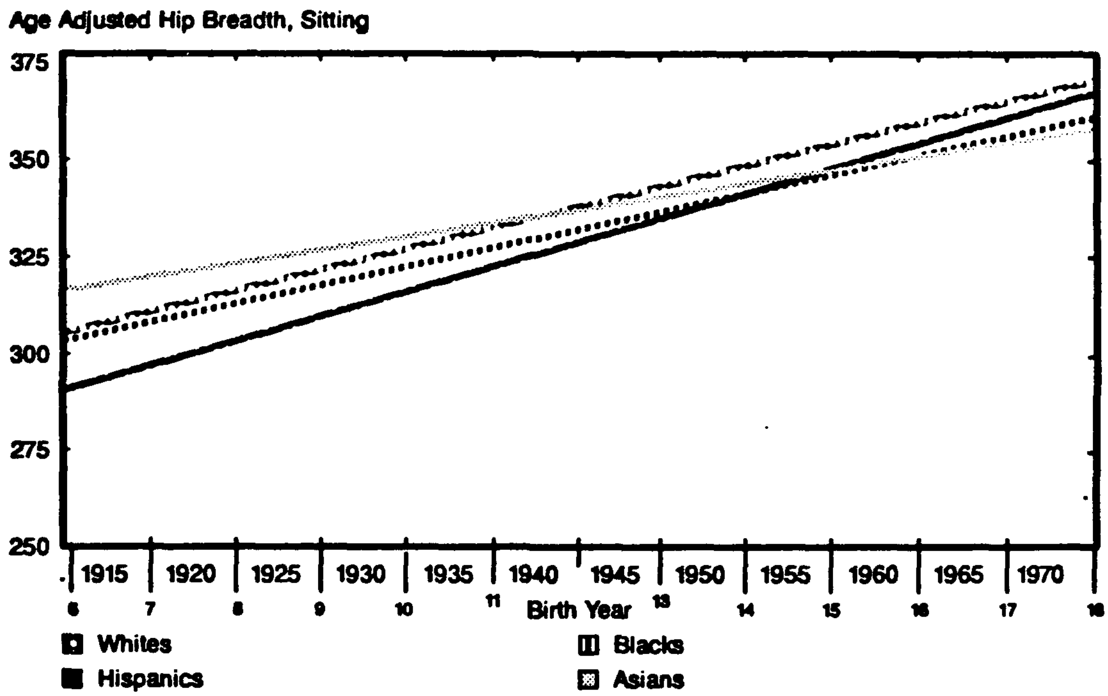

Figure 18. Secular Change of Hip Breadth, Sitting

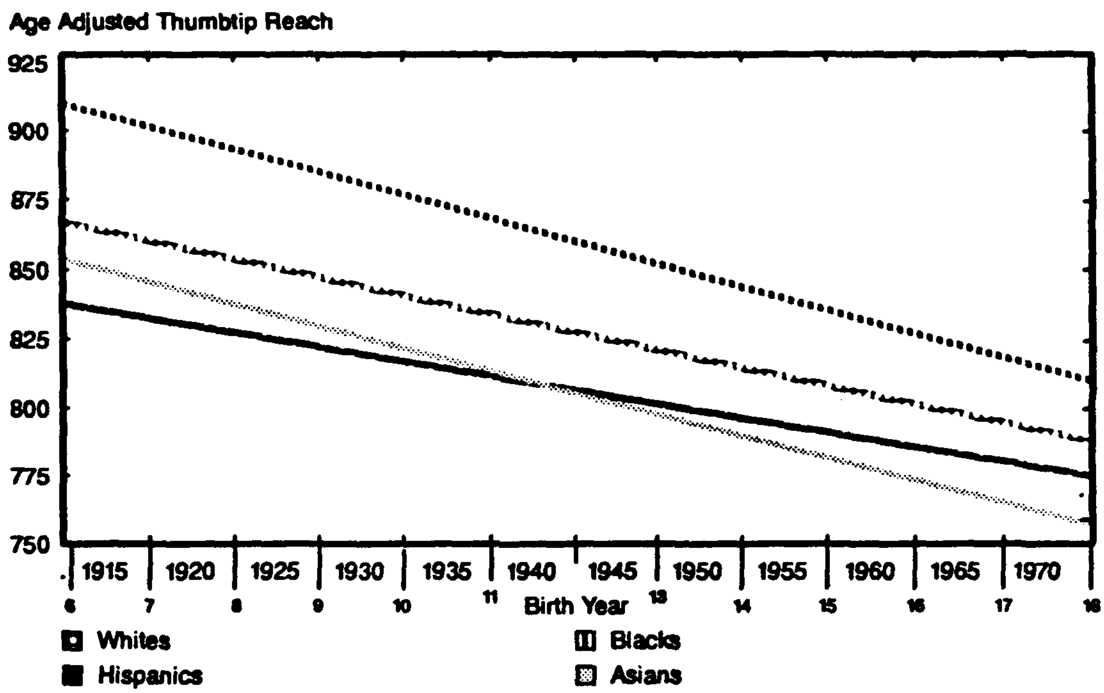

Figure 19. Secular Change of Thumbtip Reach

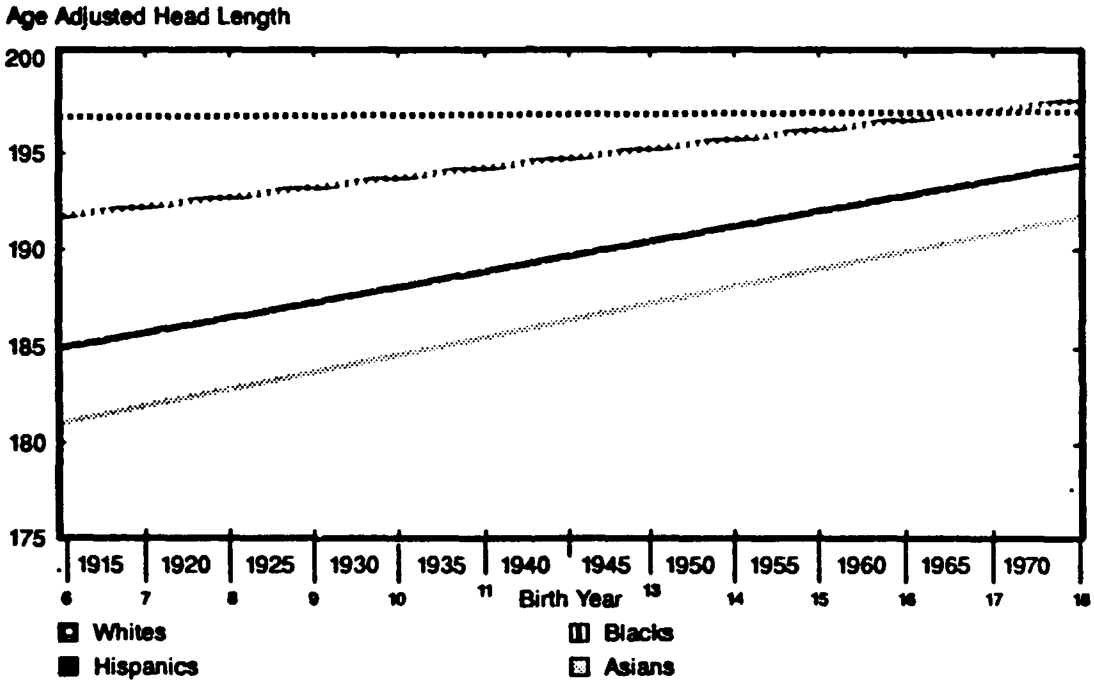

Figure 20. Secular Change of Head Length

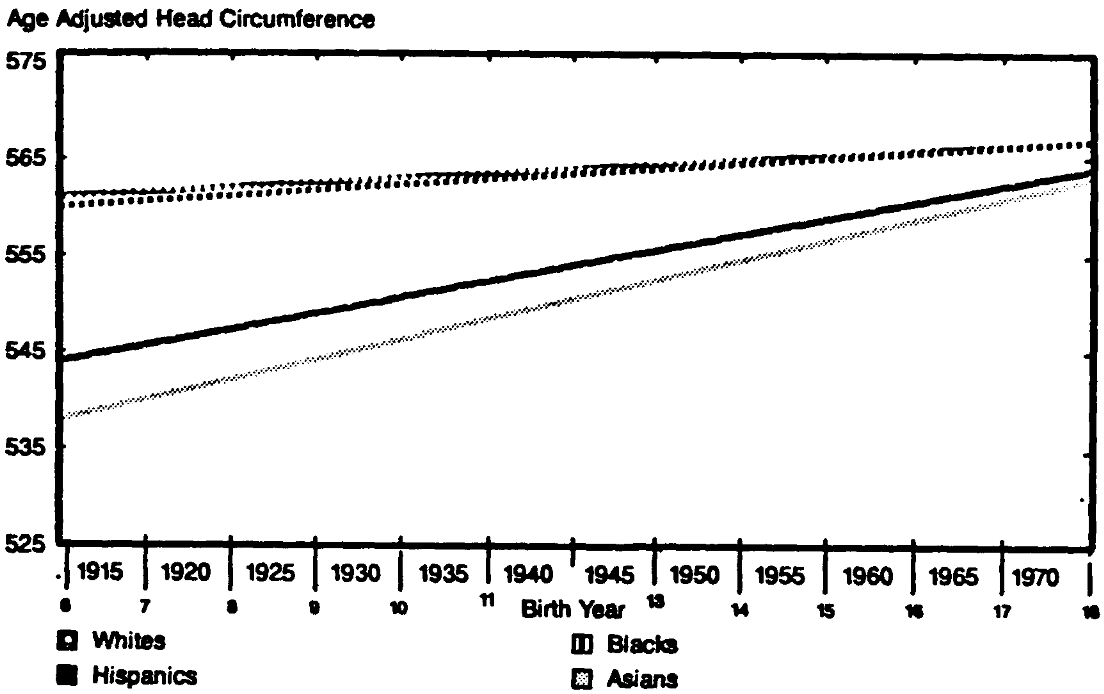

Figure 21. Secular Change of Head Circumference

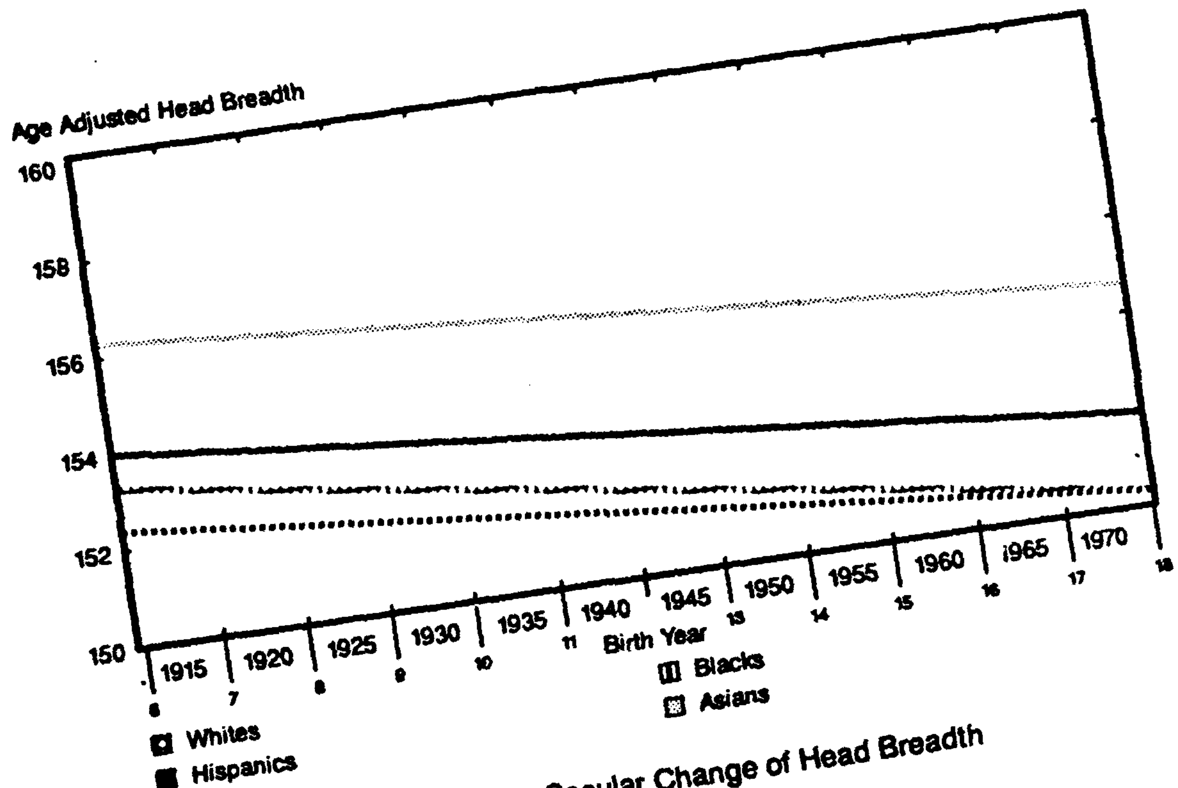

Figure 22. Secular Change of Head Breadth

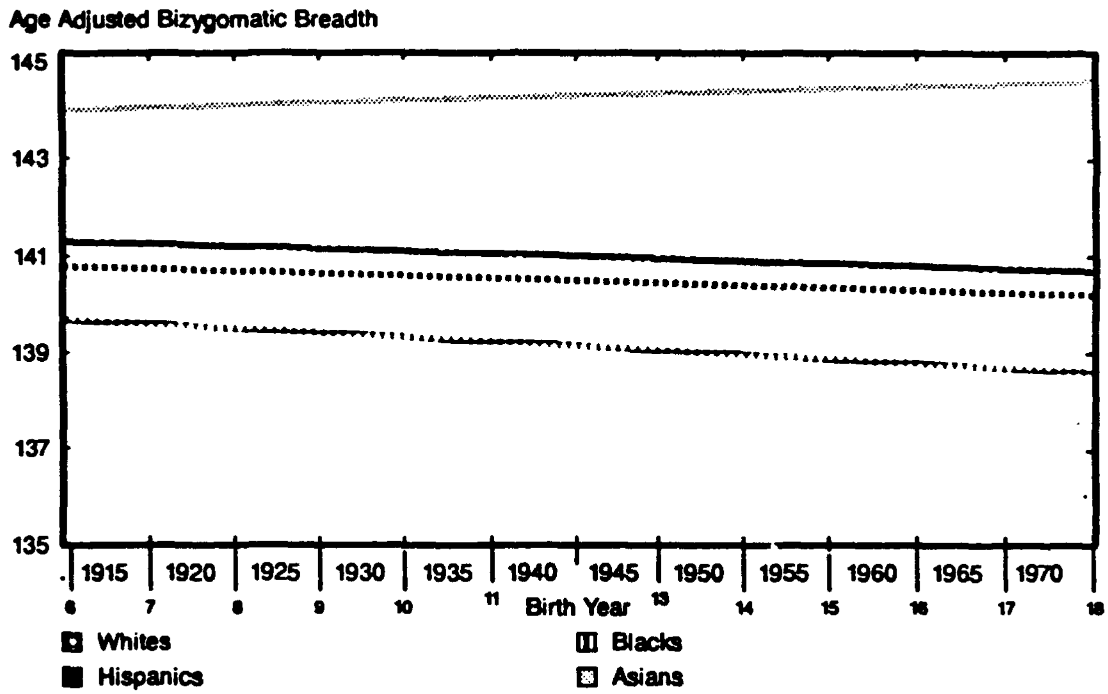

Figure 23. Secular Change of Bizygomatic Breadth

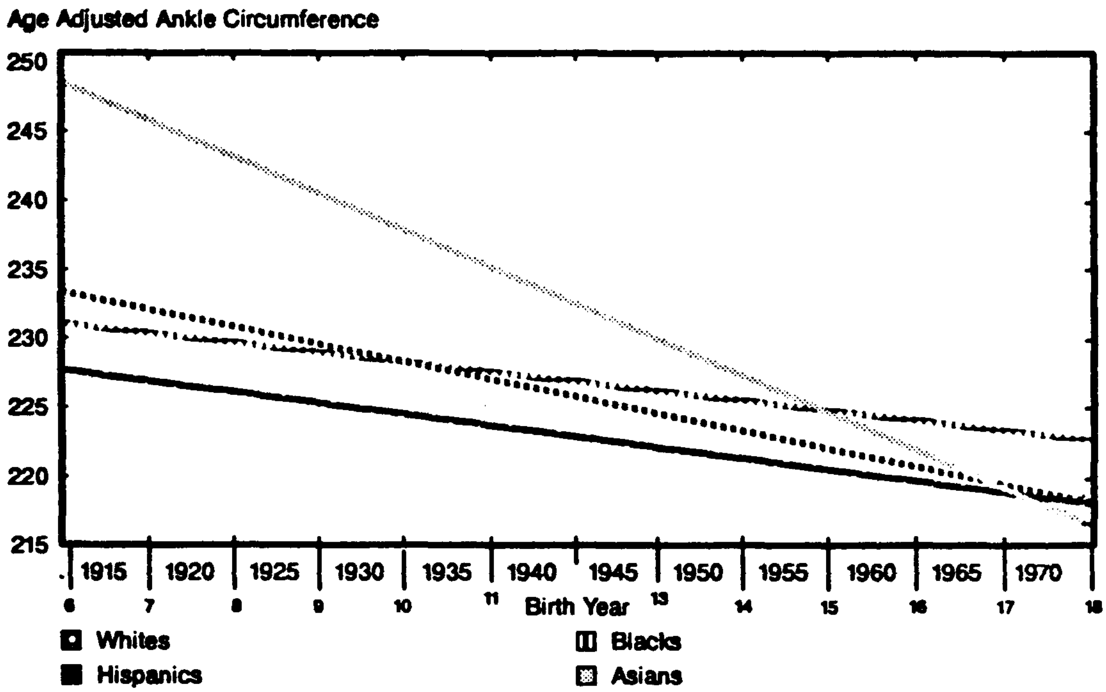

Figure 24. Secular Change of Ankle Circumference

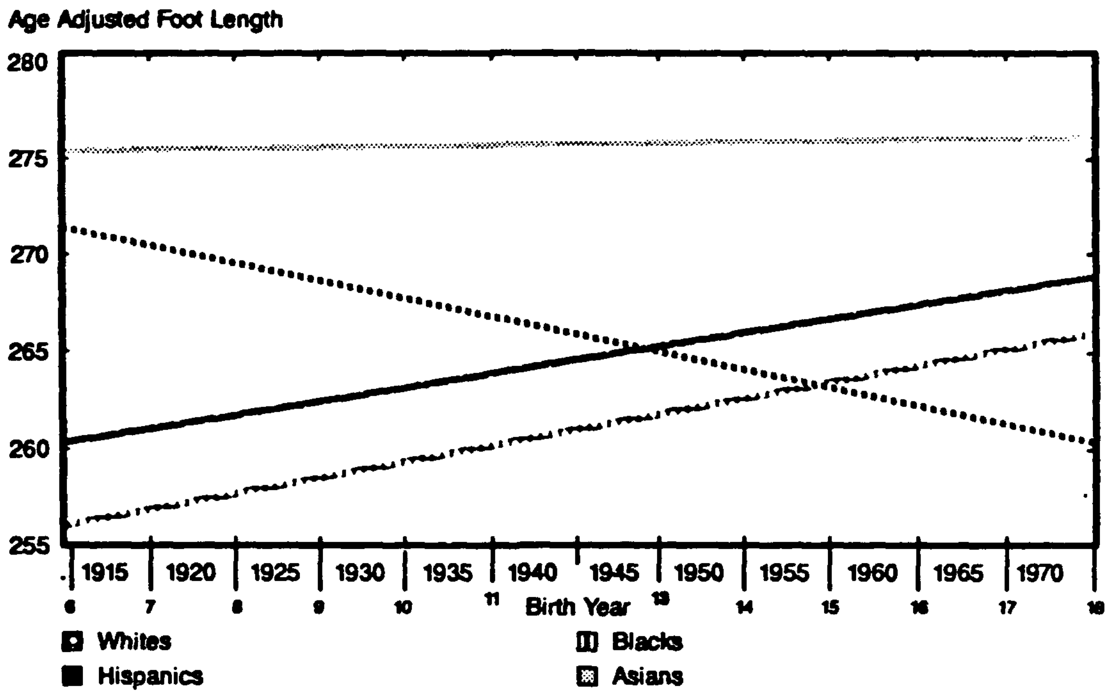

Figure 25. Secular Change of Foot Length

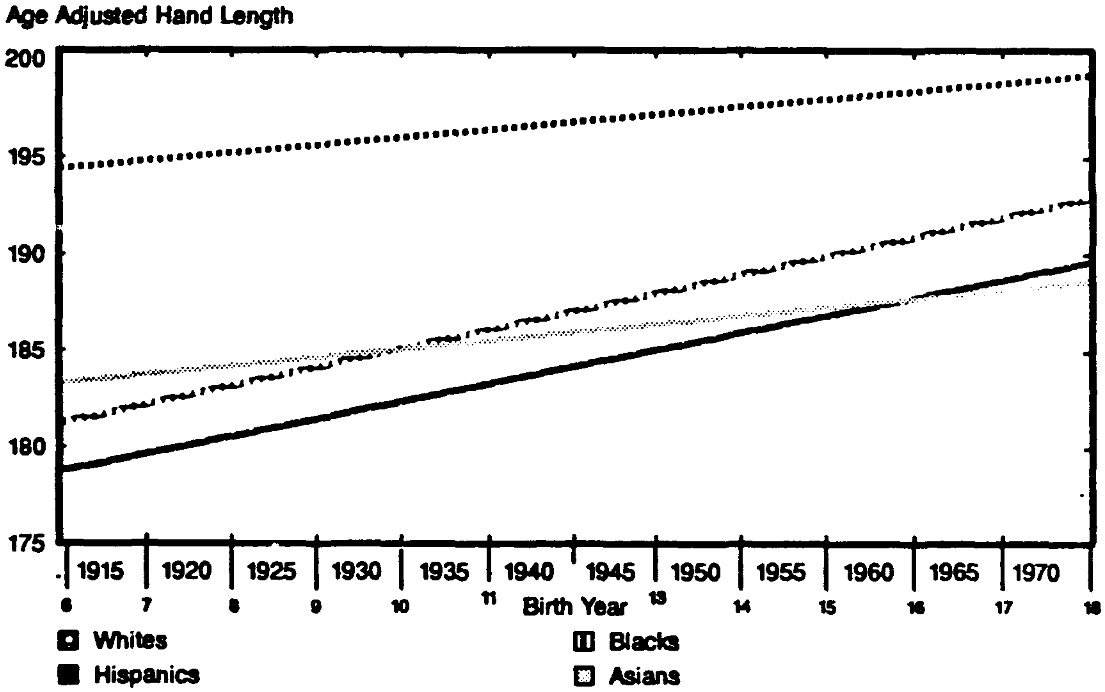

Figure 26. Secular Change of Hand Length

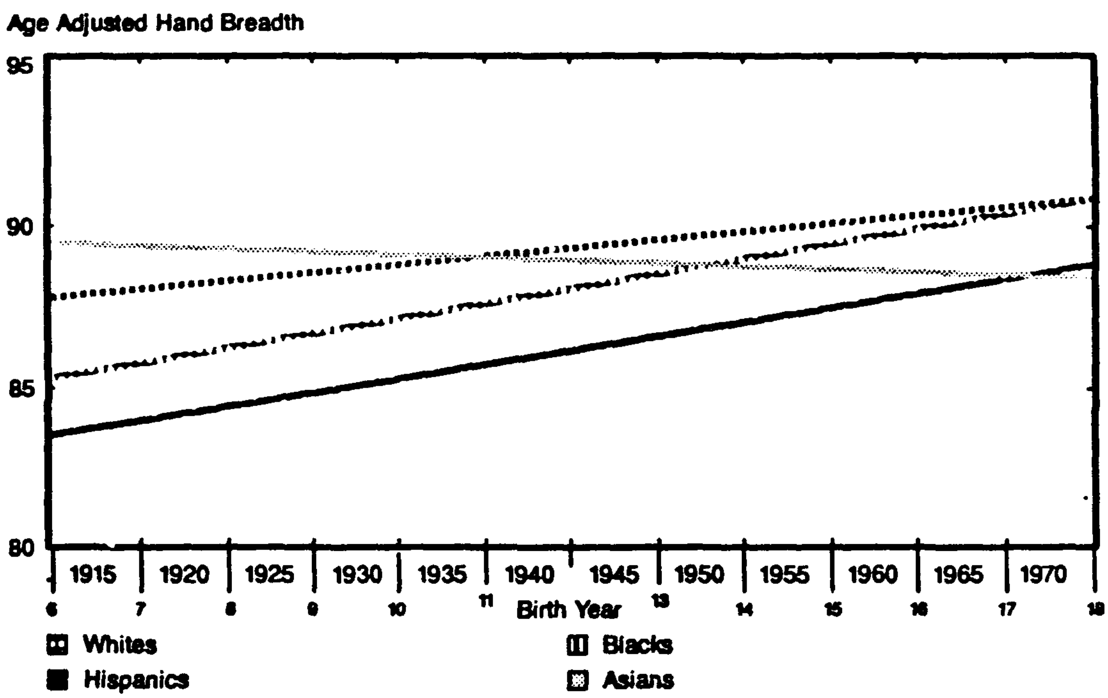

Figure 27. Secular Change of Head Breadth

9. APPENDIX II

Program Source Code for Predicting Future Anthropometric Dimensions

```
program Predict_Anthropometric_Dimensions;

{Thomas M. Greiner, Research Anthropologist, US Army Natick}
{April 1990}

{$N+} {Turns on Math Coprocessor}

uses crt;

Type
  RaceData=Record
              Prop:double;
              NumCoh:byte;
              Cohort:array[1..100] of byte;
              CohProp:array[1..100] of double;
             End;

Var
  Whites, Blacks, Hispanics, Asians : RaceData;
  YearofInterest, RoundYear : word;
  fni, fno : text;

procedure readdata;
  var
    inputfile, Outputfile : String[70];
    Counter : byte;

  begin
    Write('Input data file name: ');
    Readln(InputFile);
    Assign(fni,InputFile);
    Write('Output data file name: ');
    Readln(OutputFile);
    Assign(fno,OutputFile);
    Rewrite(fno);
    Reset(fni);
    readln(fni,Yearofinterest);
    if (YearofInterest mod 5)=0 then RoundYear:=
                                       (YearofInterest-1900) div 5
      else RoundYear:=(((YearofInterest div 5)*5)-1900) div 5;
    Readln(fni,Whites.prop);
    Readln(fni,Whites.NumCoh);
    For Counter:=1 to Whites.Numcoh do
```

```
      Readln(fni,Whites.Cohort[Counter],Whites.CohProp[Counter]);
    Readln(fni,Blacks.prop);
    Readln(fni,Blacks.NumCoh);
    For Counter:=1 to Blacks.Numcoh do
      Readln(fni,Blacks.Cohort[Counter],Blacks.CohProp[Counter]);
    Readln(fni,Hispanics.prop);
    Readln(fni,Hispanics.NumCoh);
    For Counter:=1 to Hispanics.Numcoh do
      Readln(fni,Hispanics.Cohort[Counter],Hispanics.CohProp[Counter]);
    Readln(fni,Asians.prop);
    Readln(fni,Asians.NumCoh);
    For Counter:=1 to Asians.Numcoh do
      Readln(fni,Asians.Cohort[Counter],Asians.CohProp[Counter]);
  End; {Readdata}

procedure CalculatePrediction;
  Var
    Counter:byte;
    WhitesVal, BlacksVal, HispanicsVal, AsiansVal : double;
    WConst, WSlope, WAgeFac,
    BConst, BSlope, BAgeFac,
    HConst, HSlope, HAgeFac, Hisp,
    AConst, ASlope, AAgeFac : double;
    VarName : String[70];
    Prediction : double;

  Begin

    While not Eof(FNI) do
    Begin
    Readln(fni,WConst, WSlope, WAgeFac,
               BConst, BSlope, BAgeFac,
               HConst, HSlope, HAgeFac,
               AConst, ASlope, AAgeFac,
               VarName);
    WhitesVal:=0;
    BlacksVal:=0;
    HispanicsVal:=0;
    AsiansVal:=0;
    For Counter:=1 to Whites.NumCoh do
      WhitesVal:=((WSlope-WAgeFac)*Whites.Cohort[Counter]+
            (WConst+WAgeFac*RoundYear))*Whites.CohProp[Counter]+WhitesVal;
    For Counter:=1 to Blacks.NumCoh do
      BlacksVal:=((BSlope-BAgeFac)*Blacks.Cohort[Counter]+
            (BConst+BAgeFac*RoundYear))*Blacks.CohProp[Counter]+BlacksVal;
    For Counter:=1 to Hispanics.NumCoh do
      Begin
       Hisp:=(HSlope-HAgeFac)*Hispanics.Cohort[Counter]+
                                            (HConst+HAgeFac*RoundYear);
       HispanicsVal:=Hisp*Hispanics.CohProp[Counter]+HispanicsVal;
```

```
    End;
   For Counter:=1 to Asians.NumCoh do
    AsiansVal:=((ASlope-AAgeFac)*Asians.Cohort[Counter]+
          (AConst+AAgeFac*RoundYear))*Asians.CohProp[Counter]+AsiansVal;
   Prediction:=Whites.Prop*WhitesVal+Blacks.Prop*BlacksVal+
                         Hispanics.Prop*HispanicsVal+Asians.Prop*AsiansVal;
   Writeln(fno,Prediction:6:2,'    ',Varname);
   End; {While Loop}

  End; {CalculatePredictions}

Begin {Main Program}
  readdata;
  Writeln(fno,'               Predicted Anthropometric Dimensions for
',YearofInterest);
  Writeln(fno);
  CalculatePrediction;
  Writeln('Completed');
  Close(fno);
  Close(fni);
End.
```

Sample Input Data File
Using Data for Population Projection A

2023	Prediction Year
.6792	Proportion of Whites
7	Number of Cohorts for Whites
25 0.020	Cohort Number followed by Proportion
24 0.387	
23 0.228	
22 0.160	
21 0.125	
20 0.071	
19 0.009	
.2652	Proportion of Blacks
7	Number of Cohorts for Blacks
25 0.01	Cohort Number followed by Proportion
24 0.34	
23 0.29	
22 0.17	
21 0.13	
20 0.05	
19 0.01	
.0394	Proportion of Hispanics
6	Number of Cohorts for Hispanics
24 0.37	Cohort Number followed by Proportion
23 0.21	
22 0.22	
21 0.12	
20 0.04	
19 0.04	
.0162	Proportion of Asians/Pacific Islanders
6	Number of Cohorts for Asians/Pacific Islanders
24 0.32	Cohort Number followed by Proportion
23 0.14	
22 0.29	
21 0.07	
20 0.07	
19 0.11	

Model Values for each Racial/Cultural Group

Whites:			Blacks:			Hispanics:			Asians/Pacific Islanders:			Dimension Name:
b	a	AF	b	a	AF	b	a	AF	b	a	AF	
53.55	1.36	2.85	63.56	0.77	2.11	49.50	1.44	2.29	74.18	-0.13	0.43	Weight
1700	3.71	3.54	1732	1.46	-1.19	1622	5.34	2.77	1791	-5.64	-8.87	Stature
365.9	0.59	2.86	389.4	-0.66	0.87	869.0	0.22	2.06	38'.6	-0.72	1.07	Neck Circumference
796.3	10.78	23.25	835.1	7.48	18.89	792.4	10.74	20.57	907 5	2.26	8.36	Chest Circumference
354.4	-0.27	-0.68	382.8	-0.76	-2.20	357.3	-0.70	-2.58	355.1	-1.53	-2.13	Calf Height

331.8	2.67	4.35	347.2	1.69	2.80	329.7	2.51	1.83	366.4	0.83	1.36	Calf Circumference
829.3	0.46	-1.12	855.7	0.44	-4.77	816.0	-0.26	-5.84	858.2	-3.88	-7.67	Crotch Height
863.6	3.57	5.14	835.6	3.21	2.39	823.8	4.27	4.91	908.4	-0.42	-0.43	Sitting Height
463.1	0.99	1.46	502.6	-0.22	-0.18	450.1	1.27	0.05	473.2	-0.51	-1.02	Forearm-Hand Length
478.2	4.68	4.35	509.6	3.55	2.87	475.3	4.09	2.46	531.5	-0.06	-1.51	Knee Height, Sitting
343.5	8.54	9.41	376.4	6.63	7.71	344.0	8.39	8.87	378.3	6.27	6.04	Bideltoid Breadth
254.9	3.78	7.79	290.7	0.97	4.58	239.2	4.63	8.42	283.5	1.43	4.29	Chest Breadth
273.1	5.41	8.01	274.9	4.77	6.98	252.4	6.37	8.38	295.7	3.46	5.54	Hip Breadth, Sitting
905.8	-6.53	-2.71	959.6	-8.34	-7.89	869.9	-5.29	-5.80	902.5	-8.11	-8.05	Thumbtip Reach
188.6	0.51	0.43	196.7	0.03	0.53	180.2	0.79	0.75	175.7	0.89	0.75	Head Length
557.5	0.52	-0.02	557.3	0.54	2.36	533.9	1.69	2.56	524.8	2.11	2.82	Head Circumference
154.8	-0.25	0.77	153.4	-0.17	0.41	155.1	-0.18	0.54	157.1	-0.14	0.49	Head Breadth
140.2	-0.09	0.91	141.1	-0.05	0.56	141.6	-0.05	0.53	143.7	0.05	0.77	Bizygomatic Breadth
235.4	-0.71	0.04	241.1	-1.28	-0.76	232.6	-0.81	-1.52	264.5	-2.67	-3.35	Ankle Circumference
256.0	0.71	1.19	275.0	0.06	-0.10	251.1	0.82	-0.02	276.9	-0.92	-2.32	Foot Length
175.3	0.98	1.51	192.0	0.40	1.16	173.2	0.91	0.97	180.7	0.44	0.29	Hand Length
82.53	0.46	0.89	86.34	0.25	0.84	80.84	0.44	0.56	89.99	-0.09	0.31	Hand Breadth

Sample Program Output
Using Data for Population Projection A

Predicted Anthropometric Dimensions for 2023

86.52	Weight
1778.25	Stature
400.11	Neck Circumference
1057.56	Chest Circumference
350.62	Calf Height
395.09	Calf Circumference
841.32	Crotch Height
938.91	Sitting Height
489.29	Forearm-Hand Length
589.37	Knee Height, Sitting
545.70	Bideltoid Breadth
341.81	Chest Breadth
402.13	Hip Breadth, Sitting
754.24	Thumbtip Reach
199.90	Head Length
570.54	Head Circumference
150.20	Head Breadth
139.83	Bizygomatic Breadth
216.49	Ankle Circumference
273.82	Foot Length
199.98	Hand Length
93.64	Hand Breadth